JAN ESKILSSON

Mitral Stenosis after Closed Commissurotomy

A Clinical and Echocardiographic Long-term Follow-up Study

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BY

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INTRODUCTION

I. SURGICAL TREATMENT OF MITRAL STENOSIS. HISTORY, TECHNIQUE AND PRESENT STATUS

Mitral stenosis, being basically a mechanical lesion, logically might be expected to lend itself to correction by surgery (3). Closed mitral commissurotomy is one of the oldest cardiosurgical procedures, and it was tried several times in the 1920's (21,129). Surgical procedures for the correction of mitral stenosis did not gain clinical acceptance until the late 1940's, when Bailey (2) and Harken et al.(53) demonstrated the feasibility and value of digital commissurotomy. Surgery for mitral stenosis produced dramatic and immediate relief to patients and long-term results have confirmed its value, although the initial hope of some observers that the results would be permanent was not borne out (31). An instrumental mitral valve dilator was introduced in 1954 (82), permitting a more extensive commissurotomy than the original digital valvulotomy and hence raising the hope of achieving more favourable long-term results (77).

Since the advent of valvular repair under direct vision in 1960, there has been a prolonged debate about the relative merits of open vs. closed mitral commissurotomy. Closed commissurotomy might still be an excellent operation in carefully chosen patients (37,120). With the increasing safety of cardiopulmonar bypass, which allows a controlled valvulotomy under direct vision, many groups have now adopted routine open commissurotomy (10,91).

Since the introduction of the ball-valve prosthesis in 1961 (130), numerous types of prosthetic valves have been evaluated. Palliative or reconstructive operations that preserve the mitral valvular function are, however, still preferred, with prosthetic replacement reserved for unsalvageable valves (47,91).

With the declining frequency of acute rheumatic fever in highly developed countries, the peak incidence of mitral stenosis presenting in young adults has now passed (11). Patients seen by cardiologists today are

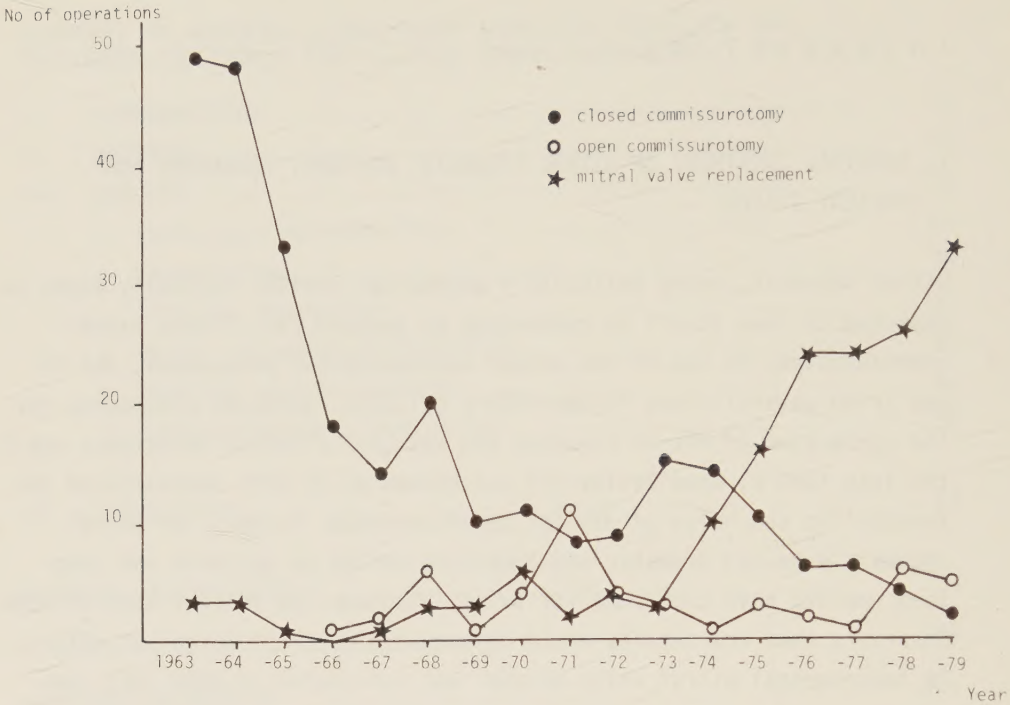


Fig.1: Mitral valve surgery, performed in Lund, 1963 - 1979.

middle-aged or elderly, often with advanced pathological changes in the mitral valve. Mitral valve replacement is often the only possible surgical procedure in this group of patients, leading to a decrease in the number of patients suitable for commissurotomy (Fig.1). In the next generation of surgeons, therefore, closed commissurotomy will be a rare skill (10).

In developing countries, however, rheumatic valvular disease is still a major problem. Rheumatic fever affects a younger group of patients in a much more severe form than in the developed countries (8). Severe mitral valve stenosis is thus seen in young patients with mobile cusps and a low incidence of atrial fibrillation, atrial thrombus, and valve calcification. In addition there are shortages of trained personnel, equipment, and drugs. For these reasons closed mitral commissurotomy has been advocated as the surgical procedure of choice for most of the patients with mitral stenosis in developing countries (8).

II. SOME FACTORS RELATED TO DETERIORATION AFTER MITRAL COMMISSUROTOMY

Although the natural history of mitral stenosis has been altered by mitral commissurotomy, recurrent symptoms are seen with increasing frequency with the passage of time after surgery (31). Mitral regurgitation and/or mitral stenosis, either recurrent or residual, are probably the causal factors in most cases (52). Secondary incompetence of the tricuspid valve may be seen in right-heart failure due to mitral valvular disease, representing the hemodynamic consequences of an increased afterload resulting in dilatation of the right ventricle and tricuspid annular circumference (109).

A deterioration might also be caused by factors unrelated to the mitral valves, e.g., coexisting aortic valvular disease or associated myocardial defects (52). Systemic embolism also represents a threat to patients with mitral stenosis, possibly diminished but not abolished by commissurotomy (48,101).

III. ECHOCARDIOGRAPHY. HISTORY AND USE IN MITRAL STENOSIS

During the last decades the echocardiogram has been used extensively to recognize rheumatic mitral valvular disease (111). The application of reflected ultrasound technique for cardiac studies was introduced in 1954 by Edler and Hertz (28). It was shown that heart structures reflect ultrasound and that echoes can be obtained from the heart in living man. Further investigations by Edler and coworkers (24,25,27) showed that there was a characteristic motion pattern of the anterior mitral leaflet in patients with mitral stenosis, although the recorded echoes originally were thought to represent left atrial wall movements. The first principal clinical application of echocardiography was thus the detection of mitral stenosis. It was subsequently demonstrated that the ultrasonic examination was useful also for quantifying the degree of stenosis and for assessing the pliability of the valve and its suitability for commissurotomy (26,51,69). The results of commissurotomy were studied by echocardiography as early as the 1950's (25,27), and since then numerous studies on mitral valve movements before and after commissurotomy have been published (for references, see Table XXVI, page 72). Some reports on the long-term echocardiographic effects of surgery on the mitral valve are now also

available (Table XXVII, p. 73), none of which, however, is extended to more than 7.5 years after commissurotomy.

A reduced rate of the anterior mitral leaflet closure is the classic criterion for the echocardiographic diagnosis of mitral stenosis (24). *An anterior movement of the posterior mitral leaflet at the beginning of diastole* has also been used as a sensitive and specific marker of mitral stenosis (23), although a normal posterior motion does not exclude the diagnosis (7,35,42,86,136). In one study, 10% of all patients with mitral stenosis showed posterior motion of the posterior leaflet during diastole (79). Following commissurotomy, the posterior leaflet may return to normal (49,64,126), but the motion pattern of the posterior mitral leaflet in long-term survivors after commissurotomy is not well known.

Echocardiography has also proven to be a valuable non-invasive method for *assessing left atrial size* (12,61). A close relationship between left atrial dimension and the occurrence of atrial fibrillation has previously been shown, using either radiologic or echocardiographic methods for assessing left atrial size (58,112,125). There are, however, different opinions as to whether the duration of the arrhythmia is also related to left atrial size (58,112).

There are also other applications of echocardiography in mitral stenosis, e.g., for the *assessment of mitral valvular calcification* (68,94).

IV. CINEFLUOROGRAPHY. HISTORY, TECHNIQUE, AND USE IN MITRAL STENOSIS

In the diagnosis, treatment, and prognosis of cardiac disease, the detection of calcification within the heart is of significance (67). The cinefluorograph, which is a standard fluoroscopic unit combined with an image amplifier tube and a motion picture camera, was introduced in the late 1950's for the detection of intra-cardiac calcific deposits (5,67). The reliability of the cinefluorographic method was established by comparing the roentgen and operative or autopsy findings (67,92).

Cinefluorography has proven to be valuable for identification and quantification of calcific deposits in the preoperative evaluation of patients with mitral stenosis (51,92). In advanced rheumatic mitral valvular disease, heavy calcific deposits are often found, but our knowledge of the rate of progress of valvular calcification is limited.

V. AIM OF STUDY

The aim of the present study was to present a current, long-term follow-up study after closed instrumental commissurotomy and to evaluate whether this surgical procedure still is a fully acceptable method of treatment in a selected group of patients with mitral stenosis. One hundred and forty-eight consecutive patients were followed for 10-15 years after their first closed commissurotomy, and the intention of the study was to analyse:

a. Early and late clinical results.

b. Long-term changes in physical working capacity.

c. Early and late echocardiographic results in terms of changes in the rate of the anterior mitral leaflet closure.

d. The incidence and rate of progress of mitral valvular calcification by means of repeat cinefluorographic examinations (including echocardiographic correlations).

e. The motion pattern of the posterior mitral leaflet in long-term survivors after closed commissurotomy.

f. The echocardiographically determined left atrial size in long-term survivors after closed commissurotomy and its relationship to age and heart rhythm.

PATIENT SERIES AND METHODOLOGY

I. PATIENT SERIES

The study is based upon a consecutive series of 148 patients undergoing their first closed instrumental commissurotomy during the period from May 1963 to the end of 1968. The indication for surgery was in all patients mitral valvular disease with pure or dominating mitral stenosis. During the same period mitral valve replacement was performed in only a few cases (Fig.1), and only in patients with dominating mitral regurgitation. From 1966 to 1968 open commissurotomy was performed in eight cases (Fig.1). These patients are not included in the study. The study thus covers 95% (148/156) of all patients operated upon because of dominating mitral stenosis during the outlined time period.

The series consisted of 97 females and 51 males, i.e., a proportion of females to males of 1.9:1. The mean age at the time of surgery was 47.4±8.4 years (±SD), with a range from 21 to 62 years. The mean age of the females was 47.9±8.5 years, as compared to 46.3±8.1 years for the males. Sixty-three patients (43%) were over the age of 50. The number, sex, and age at the time of surgery of the entire patient series, as well as of the different, separately studied sub-samples, are shown in Table I.

II. PREOPERATIVE EVALUATION

Some preoperative characteristics of the patients are summarized in Table I.

Fifty-eight patients (39%) had *atrial fibrillation*. The mean age of these patients was 51.2±6.1 years. The mean age of the remaining 90 patients in sinus rhythm was 44.9±8.7 years. The age difference between the two groups is statistically significant ($p<0.001$).

Table I: Preoperative characteristics of the entire patient series and of different sub-samples.
AF = atrial fibrillation; AVD = aortic valvular disease; MR = mitral regurgitation.

		No. of patients	Age $\bar{x}$	Age SD	Females n	Females %	AF n	AF %	Valvular Calcific. n	Valvular Calcific. %	AVD n	AVD %	MR n	MR %
All patients →		148	47.4	8.4	97	66	58	39	36[a]	25	45	30	63	43
Patients surviving surgery ≥10 years	Total	123	46.9	8.6	83	67	45	37	28[b]	23	37	30	48	39
	with long-term exercise test evaluation	65	42.9	7.4	43	66	17	26	17[c]	27	17	26	27	42
	with long-term echocardiographic evaluation	108	46.5	8.7	71	66	39	36	25[b]	24	32	30	42	39
	with long-term cinefluorographic evaluation	100	45.8	8.6	68	68	35	35	23	23	31	31	40	40
	with postoperative evaluation of posterior mitral leaflet motion	107	46.1	8.5	70	65	40	37	25[b]	24	34	32	41	38
	with postoperative determination of left atrial size	109	46.5	8.7	73	67	39	36	24[b]	22	34	31	42	39

Cinefluorography not performed in a) six cases b) two cases c) one case.

A preoperative cineflurographic examination was performed in 142 patients. *Calcific deposits in the mitral valves* were found in 36 patients (25%). The incidence of valve calcification was 39% and 18% in males and females, respectively. Heavy calcification (cf. p. 28) was observed in seven patients (4.9%), with an incidence of 8.2% in males and 3.2% in females.

Many patients had some degree of *mitral regurgitation*, although the indication for commissurotomy in all patients was pure or dominating mitral stenosis. During commissurotomy mitral regurgitation was found in 63 patients (43%), as estimated by the surgeon before the dilatation of the valve. In most cases the regurgitation was trivial, but in thirteen patients (8.8%) a regurgitant jet was palpable three fingers or more from the mitral orifice.

Physical signs of concomitant *aortic valvular disease*, i.e., a systolic murmur of crescendo-decrescendo type with maximal intensity in the second right intercostal space and/or an early, high-pitched diastolic murmur at this site and along the left sternal border, were found in 45 patients (30%). The diagnosis was confirmed by left heart catheterization and angiocardiography in seventeen cases. The highest recorded peak systolic pressure gradient across the aortic orifice was 35 mm Hg.

On the basis of the subjective symptoms during daily life the patients were grouped into *functional groups* according to the criteria of the New York Heart Association (96), as modified by Bishop and Wade (9):

Class I: Patients with no disability.
Class II: Patients whose physical activity is not impaired except when undertaking severe or competitive physical exercise or heavy work.
Class III A: Patients who suffer from slight discomfort in the normal activities of life but are able to walk an English mile or more on flat ground at their own speed and can climb stairs slowly without undue discomfort.
Class III B: Patients who can manage only the lightest of activities without discomfort, who can walk only short distances on flat ground without resting and have difficulties in going upstairs.
Class IV: Severely disabled patients confined to bed or chair.

Preoperatively, a uniform functional classification was performed only on the first 67 patients in the present series. These patients were described by Gustafson in 1966 (51). According to his classification three patients belonged to group I; 23 to group II; 29 to group III A; and 12 to group III B. Based on a retrospective review of the clinical records, the remaining group of 81 patients seemed to be slightly more disabled at the time of surgery compared to the first group, with no patients in functional class I and a greater percentage of patients in functional classes III A - III B. Due to the uncertainty of a retrospective judgement, no definite classification of these patients was made.

III. SURGICAL TECHNIQUE

Mitral commissurotomy was performed by means of transventricular dilatation according to Logan and Turner (82). The patients with atrial fibrillation were treated with dicoumarol for at least three weeks before surgery. Additional surgical procedures were aortic valvotomy (one patient) and pericardectomy because of constrictive pericarditis (one patient).

IV. METHODOLOGY

a. Design of study

After surgery many patients were followed at the Department of Cardiology, University Hospital, Lund. A late follow-up study was started at the end of 1978 and was, with the exception of three patients, completed during the first half of 1979. At the end of 1978, 109 patients were still alive (Fig.2). A second heart operation had been performed in 17 patients, including mitral valve replacement in ten patients, mitral and aortic valve replacement in two patients, second closed commissurotomy in four patients, and closure of a cleft in the anterior mitral leaflet caused by surgery in one patient. There were 102 patients who had not undergone mitral valve replacement who were still alive at the time of the follow-up study (Fig.2). A late postoperative examination was performed by the author in 99 of these cases at an average of 13.8 years (range, 10.1 to 15.8 years) after surgery.

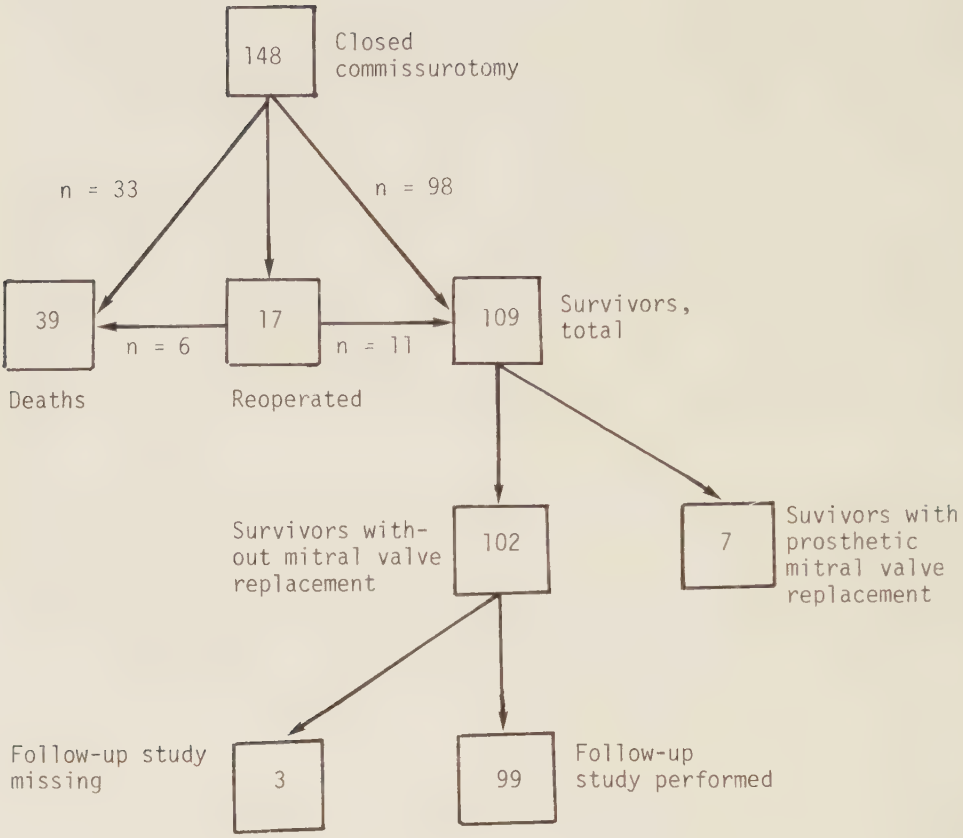


Fig. 2: Status on December 31, 1978, of patients who underwent closed commissurotomy between May 1963 and the end of December 1968, and breakdown of patients in late follow-up study performed by the author. Figures indicate number of patients.

It was not possible to perform a late follow-up study in three patients, due to one patient's lack of interest and time and to old age and disabling disease in two patients. The history of each of these patients has been obtained by telephone contact, and the clinical records were obtained from their local hospitals.

In patients operated on more than once, information from the evaluation prior to the second heart operation was used. The clinical records of the deceased patients were all reviewed, and complete records were available on all but two patients.

b. Clinical follow-up study

The study on early and late clinical results was based on reviews of the clinical records of the patients, the history obtained at the late follow-up study, and the findings either at the late follow-up study or at previous clinical examinations performed at least 10 years after the commissurotomy. In five cases, left heart catheterization with cineangiography was performed within 9 months after the follow-up investigation. The findings at these examinations were also included in the study.

All deaths during surgery and those within 30 days postoperatively or before discharge from hospital were considered as *perioperative mortality*. The causes of late death have been obtained either from the hospital records or from the official death certificates; in most cases autopsy was not performed.

At the late follow-up study a routine physical examination was performed, and a 12-lead electrocardiogram (ECG) and phonocardiogram were recorded. An eight-channel direct writing ECG-apparatus (Mingograph 81, Elema-Schönander) was used for these examinations. The following ECG-leads were used: aVL, I, -aVR, II, aVF, III, and precordial leads V1-V6. Phonocardiograms were recorded from the apex, the fourth, third, and second left and the second right intercostal spaces. The frequency bands with a nominal frequency of 25, 50, 100, 200 and 400 c/sec were used.

A *late functional classification* according to the New York Heart Association (NYHA), as described on page 14, was performed only in patients seen by the author at the late follow-up study, and only in patients who had undergone no secondary procedure to the mitral valve. Some of these patients were seriously disabled because of non-cardiac diseases, e.g., arthrosis or hemiparesis, making a functional classification inappropriate. It was possible to perform a functional classification 10-15 years after surgery in 92 of 99 patients.

An assessment of the presence of *mitral regurgitation* was performed in single operated patients using either of the following two methods:
1) A left heart catheterization with left ventricular cineangiography was performed in 22 patients 10-15 years after surgery. The mitral regurgitation was graded as severe (+++), moderate (++), light (+) or

absent (0). 2) Heart auscultation and phonocardiographic recordings were used in an attempt to diagnose mitral regurgitation in another 87 patients, all examined by the author or by colleagues at the Department of Cardiology in Lund 10-15 years after surgery. A high-frequency pansystolic apical murmur of moderate or loud intensity was thought to represent a moderate or severe mitral regurgitation (++/+++). A faint medium or high-frequency apical murmur, not audible in the left axillar line, was classified as representing a light mitral regurgitation (+). Patients without apical systolic murmurs were classified as not having mitral regurgitation (0).

The incidence of *aortic valvular disease* 10-15 years after surgery was evaluated by left heart catheterization, including left ventricular cineangiography and supravalvular aortography, in 23 patients. Heart auscultation and phonocardiography were used in diagnosing aortic valvular disease in another 89 patients, using the same diagnostic criteria as in the preoperative assessment, as described on page 14.

The incidence of *tricuspid regurgitation* was assessed by external venous pulse curve analysis in 98 patients. Pulse curves from the jugular bulb and liver were recorded by a capillary-damped funnel pick-up connected with an air-containing rigid latex tubing of an Elema-Schönander EMT 510 C crystal transducer (140,143). A direct writing ink-jet Mingograph 81 with paper speed of 100 mm/sec was used for the simultaneous recording of the electrocardiogram, phonocardiogram, and external pulse curves. A tricuspid regurgitation was considered to be present if the pulse wave contours from the jugular bulb and liver could be grouped into either of the following two types: 1) the normal x-descent was completely obliterated and replaced by a large systolic wave (ventricularization) (Fig.3); or 2) an abbreviated x-descent was followed by a regurgitant wave in late systole, exceeding the v-wave or merging with it (Fig.4).

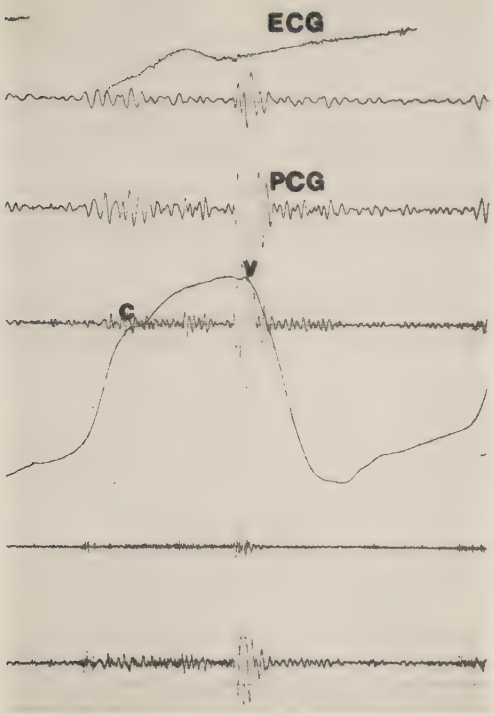


Fig. 3: panel a.

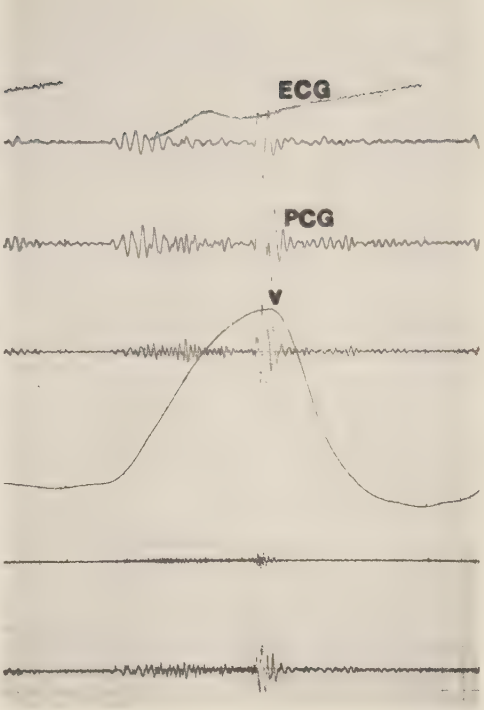


Fig. 3: panel b.

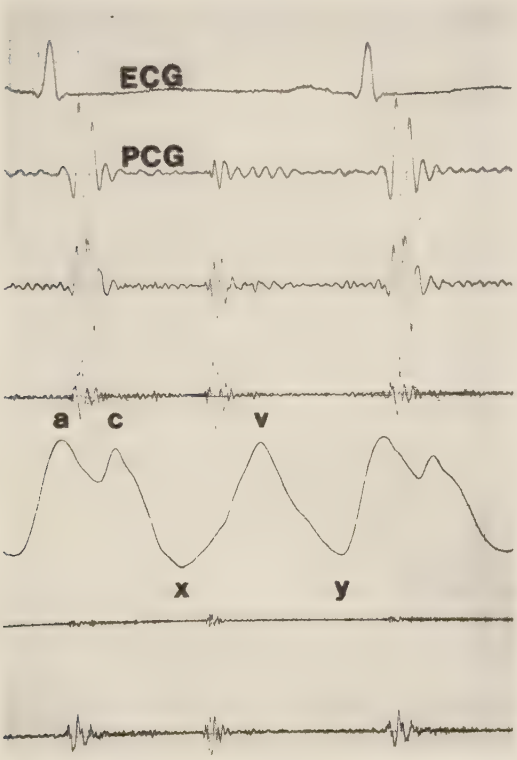


Fig. 3: panel c.

External pulse wave recordings from the jugular bulb (panel a) and liver (panel b) in a patient with ventricularization of the pulse wave contours. A normal recording from the jugular bulb is shown in panel c for comparison.

ECG = electrocardiogram
(pacemaker in panels a+b)

PCG = phonocardiogram

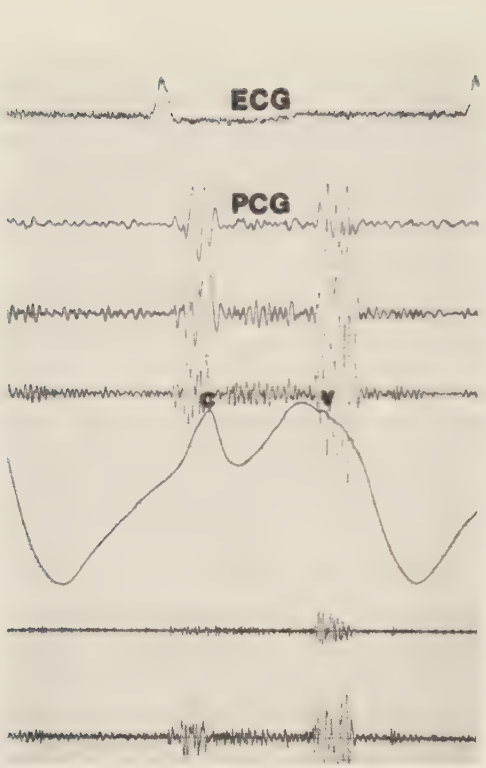


Fig. 4: panel a.

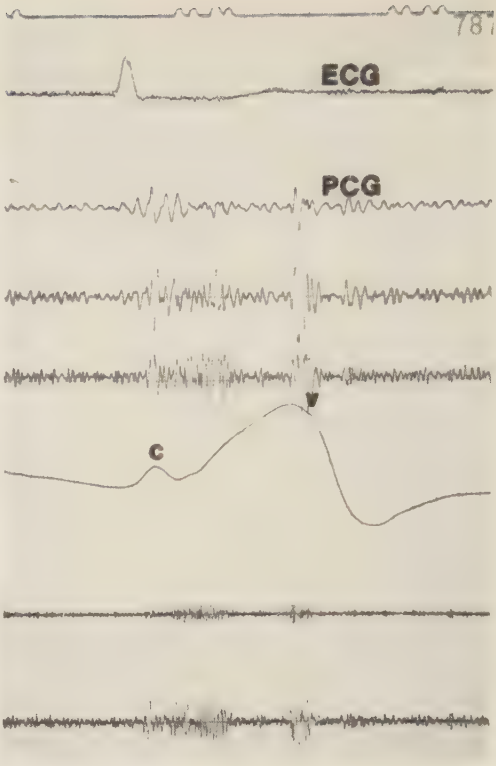


Fig. 4: panel b.

External pulse wave recordings from the jugular bulb (panel a) and liver (panel b) in a patient with a regurgitant wave in late systole, exceeding the v-wave.

ECG = electrocardiogram; PCG = phonocardiogram.

The incidence of *systemic embolism* after commissurotomy was investigated in patients surviving the perioperative period (n=143). The study was based on a retrospective review of the clinical record of each patient. Two patients were excluded from the study because of incomplete data. The remaining 141 patients were followed for a total period of 1.761 patient-years. Death and prosthetic mitral valve replacement were the only end-points during the first decade after commissurotomy. The follow-up period was otherwise in the range from 10.1 to 15.8 years.

c. Exercise test evaluation

The exercise test was performed with the patient sitting on an electrically braked bicycle ergometer (62). Initial workload was usually 200 kpm/min or 30 Watt (W) for women, and 300 kpm/min or 50 W for men. The workload was increased step-wise by increments equal to the initial

workload according to the principles described by Sjöstrand (127). The patient performed the exercise test until marked symptoms appeared, usually marked dyspnea or exhaustion. In some cases the test was interrupted because of ventricular ectopic beats of increasing frequency, and in a few cases the test was stopped on account of a high heart rate, 170 beats/min or more. The exercise test was judged as inconclusive and was excluded from the study if it was interrupted due to these disturbances of heart rhythm.

The physical working capacity (PWC), expressed in kpm/min or W, was in most cases calculated as the highest workload which the patient was able to maintain for six minutes. If one to five minutes of working was possible also on the next workload, PWC was proportionately elevated, according to Granath (46). Thus

$$PWC = W_6 + \frac{n \times W_d}{6}$$

were W_6 is the highest load maintained for six minutes, n the number of minutes on the higher load and W_d the difference between the loads. The same formula was also used for calculating PWC in those patients unable to maintain even the initial workload for six minutes, a situation which occurred in 7.5% of the exercise tests.

The PWC, expressed as the percentage of the expected normal value (PWC%), was also calculated in each patient in order to eliminate the influences of age and sex on the working capacity. The normal values, as presented at a meeting of the European Society of Cardiology in 1980 by Nordesjö (99), are based on a pooling of data from several European studies. (See appendix!)

In the evaluation of PWC the results were furthermore correlated to individual height, weight and body constitution (99).(See appendix!)

A conclusive exercise test was performed preoperatively in 135 of the 148 patients. The test was inconclusive in nine patients and not performed in four.One hundred and twelve of these 135 patients survived commissurotomy for more than one decade without any secondary procedure to the mitral valve. A conclusive exercise test was performed in 65 of these

patients 10-15 years after surgery (mean 13.5±1.7 years, range 10.1 to 15.8 years), either at the late follow-up study or at previous examinations performed at least 10 years after the commissurotomy (Fig.5). Some pre-operative characteristics of this sub-sample of patients are given in Table I (page 13).

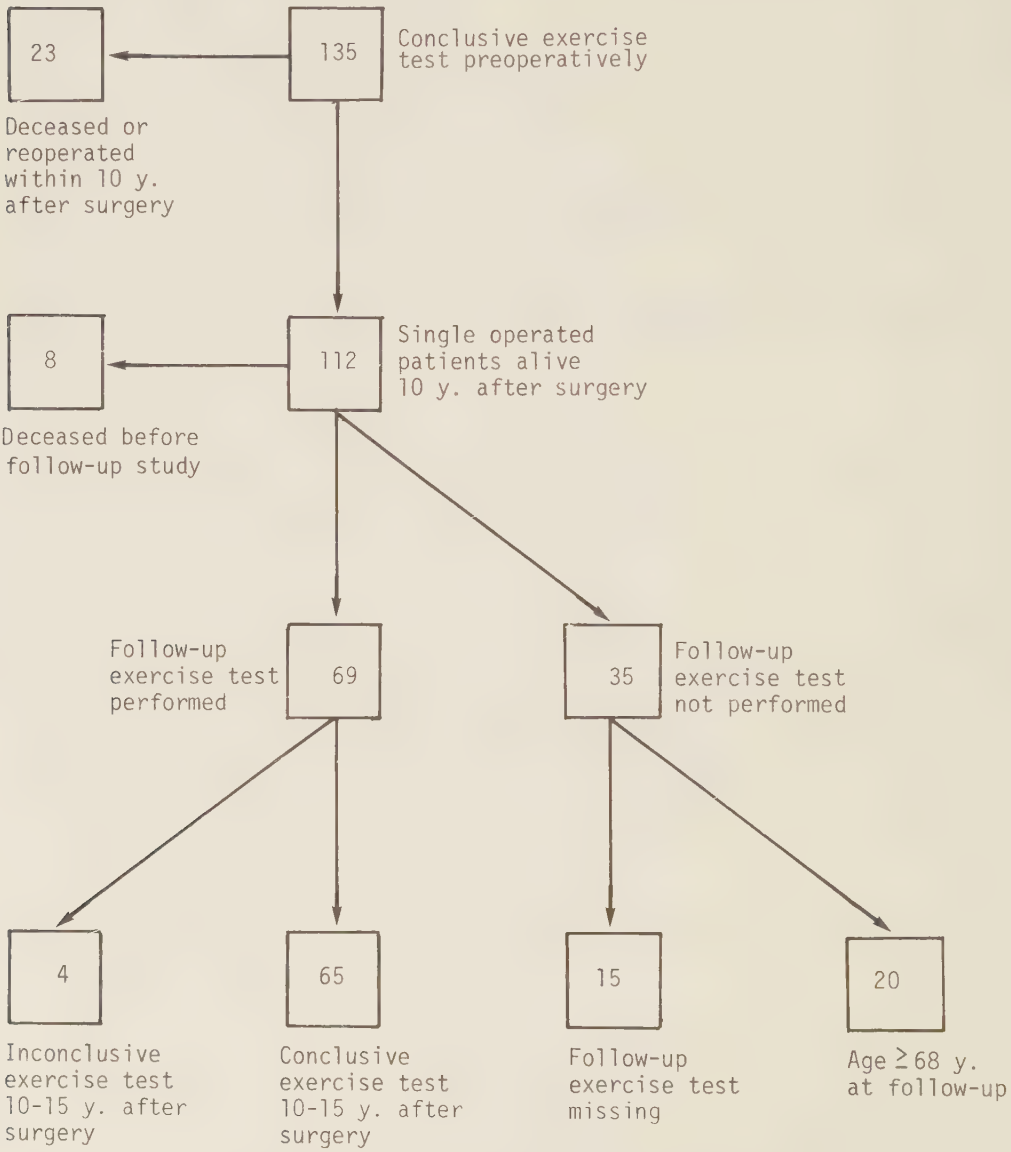


Fig. 5: Exercise tests before and 10-15 years after commissurotomy. Figures indicate number of patients; y. = years.

The selected group of patients with late follow-up investigation (n=65) was further subdivided into three groups according to their heart rhythms. Group I consisted of 32 patients (13 males, 19 females) with stable sinus rhythm. Group II included 16 patients (four males, 12 females) who had sinus rhythm at the time of surgery and atrial fibrillation at the follow-up study. Group III consisted of 17 patients (five males, 12 females) with atrial fibrillation both pre- and postoperatively.

An exercise test was not performed in 35 patients at the late follow-up study (Fig.5). Twenty patients were excluded because of old age (above 67 years). In another six patients a work test could not be performed because of disabling non-cardiac diseases, e.g., hemiparesis, arthrosis, and fractures. Pacemaker rhythm (one patient) and intermittent arrhythmia, occurring at the time of the study (two patients), were other exclusion criteria. One patient, being in functional class IV (NYHA), was unable to perform a work test, and two patients refused. Due to practical problems it was impossible to coordinate the clinical examination with an exercise test in the remaining three patients.

d. Echocardiographic evaluation of the anterior mitral leaflet motion

The echocardiographic recordings were performed with the patient in the recumbent position with the chest slightly elevated (10-20 degrees). The recordings were usually made from the third or fourth intercostal space at varying distances from the midsternal line. The latter distance was determined by the possibility of obtaining satisfactory tracings. At the recordings the transducer was held as vertically as possible.

Two variables were determined in every echocardiographic tracing: *the rate of diastolic descent (E-F slope)*, i.e., the speed of the initial diastolic downstroke E to F_o; and *the amplitude of excursion from D to E (D-E amplitude)* (Fig.6). For measurements, the tracings with the largest amplitude were used. The E-F slope was determined as the mean value of the early diastolic descent-rate during 5-10 consecutive heart cycles in 67% of the echocardiograms. The mean E-F slope was calculated from 4-10 heart cycles including 2-4 consecutive beats in another 29% of

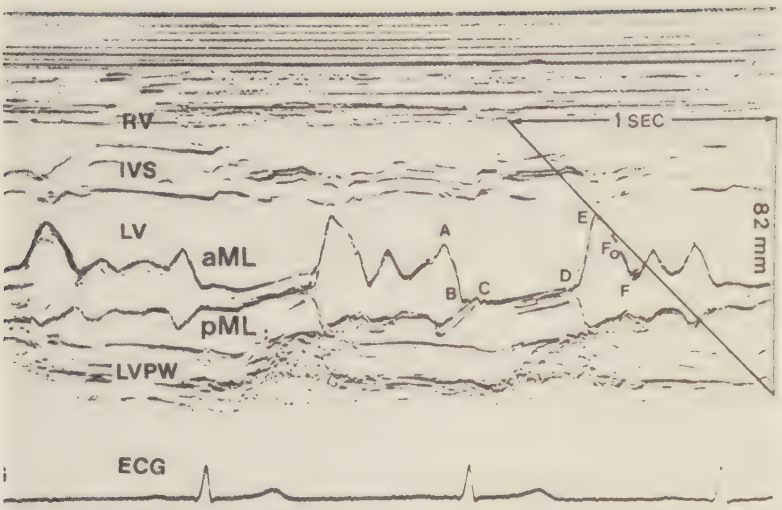


Fig. 6: Normal mitral valve echogram with measurement of E-F slope
RV = right ventricle; LV = left ventricle; IVS = intraventricular septum; LVPW = left ventricular posterior wall; aML = anterior mitral leaflet; pML = posterior mitral leaflet; ECG = electrocardiogram.

the echocardiograms, and from 2-4 single beats in the remaining 4%. The reasons for this were technically limited recordings or ventricular ectopic beats or the use of polaroid recording technique. The D-E amplitude was calculated as the largest amplitude of excursion of the anterior mitral leaflet obtained in those heart cycles that were used for the E-F determination.

The term *restenosis* was applied to patients with an E-F slope ≤20 mm/sec during the follow-up after commissurotomy.

The first equipment used was an ultrasound reflectoscope (Ultraschall Impulsgerät II) manufactured by Siemens Reiniger Werke, Erlangen, Germany. This apparatus, used until 1965, has previously been described by Edler (26). The pulse frequency of the apparatus was 200/sec. A barium titanate crystal with a frequency of 2.5 MHz was used. The echocardiograms were

recorded by the direct-writing method described by Hertz (59). This method permits recording of only one ultrasound curve, but permits the correlation between echocardiogram and simultaneously recorded electrocardiogram and phonocardiogram. The electrocardiograph used for the recording was a Mingograph 42(Elema, Stockholm).

From 1965 to 1975 the echocardiograms were recorded using a Smith-Kline Ekoline 20 ultrasonoscope and a 2.25 MHz transducer, with a pulse frequency of 1000/sec. Towards the end of this period a photographic recording of the echocardiogram was used (26). By this method, echo signals from a structure that moves to and fro are reproduced on a film as a curve (M-mode). The film shows curves representing each of the sound-reflecting structures. In most cases, however, the direct-writing method was used, and in some cases the M-mode echocardiograms were recorded by polaroid photographs.

After 1975 the echocardiograms were, with just a few exceptions, recorded using an Organon Teknika Echocardiovisor 01 attached to a strip chart recorder (Honeywell LS-6). A 2.25 MHz transducer with a pulse frequency of 1024/sec was used.

The study was based on a review of 1.678 echocardiographic recordings, obtained from the entire series of 148 patients from the time immediately prior to surgery onwards. All echocardiograms have been reviewed by the author. A 10-15 year follow-up echocardiogram was obtained in 108 single operated cases at an average of 13.5±1.7 years after surgery, either at the late follow-up study or at previous examinations at least 10 years after the commissurotomy, with a range from 10.1 to 15.8 years. Some pre-operative characteristics of these patients are given in Table I (page 13).

During the follow-up of patients in the present series a large number of echocardiograms were obtained at widely scattered time intervals after surgery. The following time intervals were chosen for comparison in order to get a comprehensive picture of changes of the E-F slope after commissurotomy: soon after surgery (within 100 days); one year (with a range from 8 to 18 months); five years (range, four to six years); and 10-15 years after surgery. The number of patients having an echocardiographic examination within these different time intervals is shown in

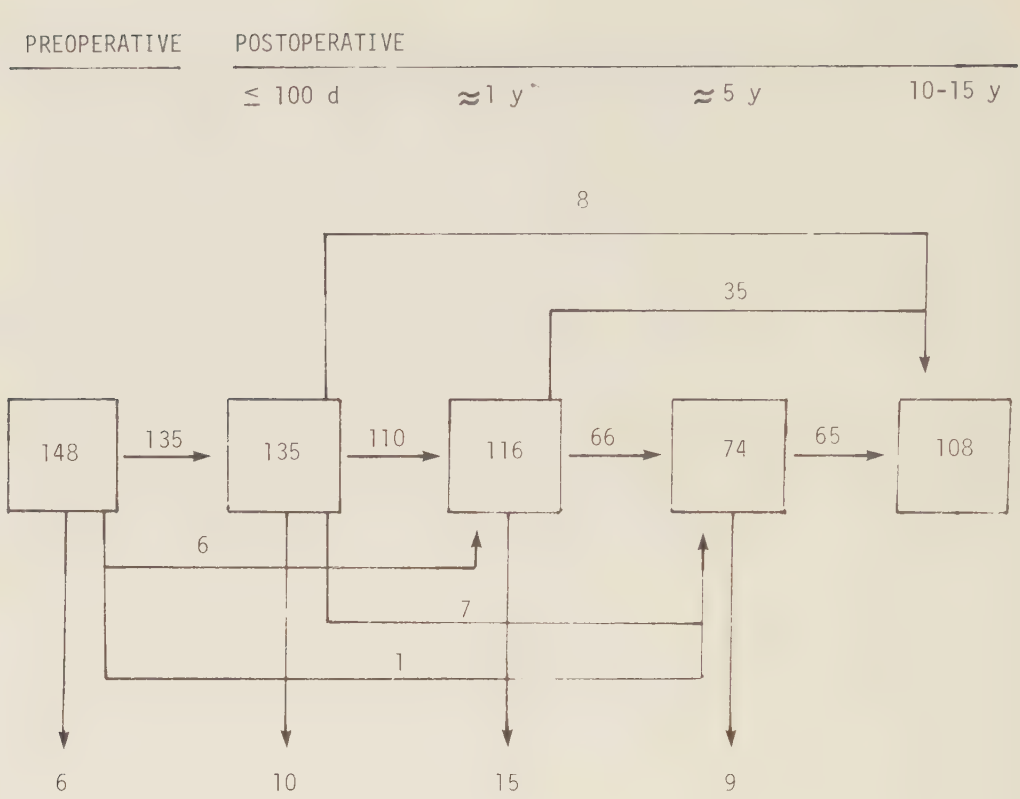


Fig. 7: Echocardiographic examinations at different time intervals after surgery. Figures indicate number of patients examined. Arrows pointing downwards indicate patients who had no further echocardiographic examination.

d = days; y = years.

Fig.7. An echocardiographic recording at each time interval after surgery was obtained in 53 patients.

An example of pre- and postoperative echocardiograms in a serially studied patient is shown in Fig.8.

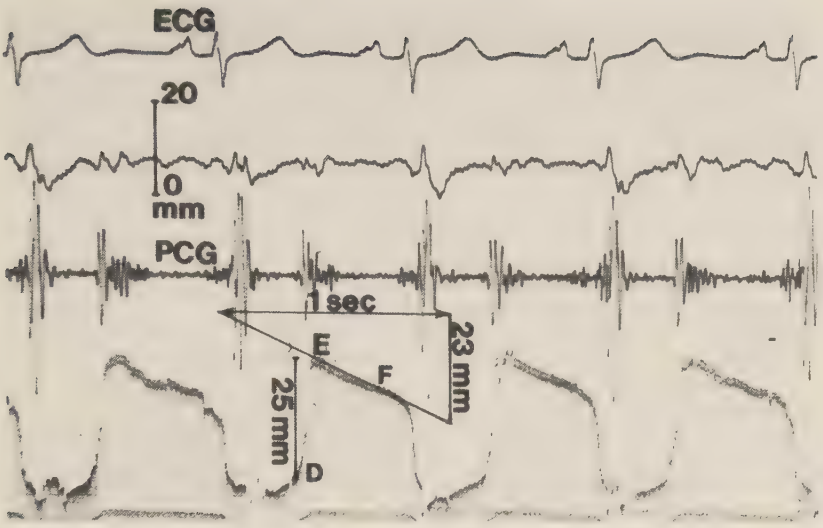


Fig. 8: Panel a.

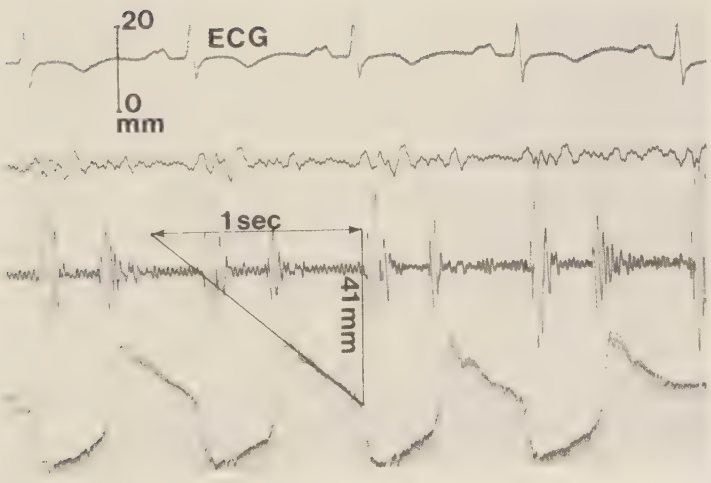


Fig. 8: Panel b.

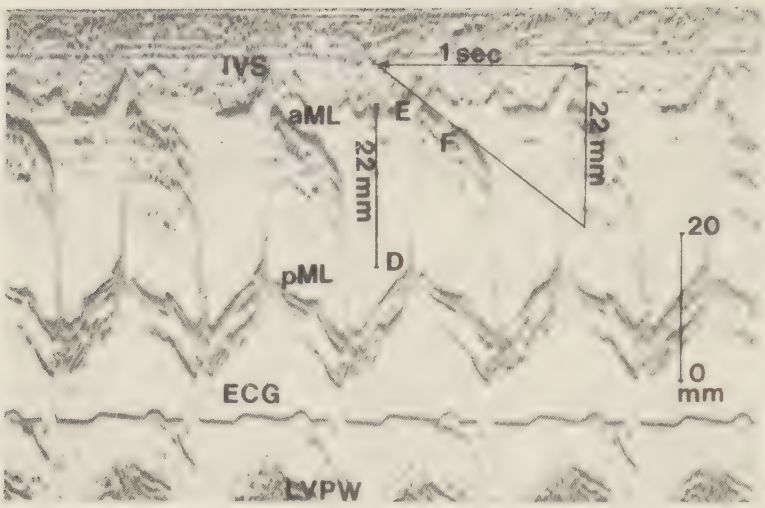


Fig. 8: Panel c.

Echocardiograms of patient with mitral stenosis before and after surgery. Panel a: Preoperative recording, March 1965. Panel b: Postoperative recording, April 1965. Panel c: 10-year postoperative recording, 1975.

Three years later, in 1978, the patient had a second closed commissurotomy because of mitral restenosis.

e. Cinefluorographic evaluation of mitral valvular calcification with echocardiographic correlations

Cinefluorography was performed during sustained inspiration in 30^{o} RAO and lateral projection. The calcifications were graded as heavy (+++), moderate (++), light (+), or absent (0). Estimation of the site of the calcifications, in the valve leaflets or in the annulus, was also tried, with full awareness of the difficulties presented by heavily calcified, non-mobile calcifications.

A cinefluorographic examination was performed in a total of 142 patients preoperatively. A 10-15 year postoperative cinefluorographic evaluation was performed in 102 patients, either at the late follow-up study or at previous examinations performed at least 10 years after the commissurotomy. Cinefluorography had not been performed before surgery in two of these

patients. In the remaining 100 patients, a comparison was made with the preoperative cinefluorographic examination and progress was noted, if present. The late follow-up investigation was performed at an average of 13.5±1.7 years after surgery, with a range from 10.1 to 15.8 years. A second closed commissurotomy had been performed in two patients at seven and eight years before the study, respectively. Some preoperative characteristics of patients included in the comparison study are shown in Table I. At the follow-up investigation the mean age of the patients was 59.3±8.5 years (range, 33 to 76 years).

In all patients with cinefluorographic evaluation, an echocardiographic examination was also performed preoperatively as well as at the 10-15 year follow-up study. At the follow-up study mitral valve calcification was evaluated according to methods previously established by Nanda et al. (94). Thin, single or duplicate diastolic echoes from the mitral leaflets were identified as coming from a non-calcified valve. Calcification was graded heavy (++) when thick conglomerate echoes were observed in diastole, and light (+) if it consisted of tiered, multiple linear echoes duplicating the mitral valve motion pattern.

f. Evaluation of posterior mitral leaflet motion

The posterior mitral leaflet motion was evaluated by echocardiography. The echocardiograms were obtained with the patient in recumbent position. The motion patterns of the posterior mitral leaflet were classified into three different types using previously established criteria (111,135). In type 1 the initial movement of the posterior leaflet, at the time of the valve opening, is anterior, i.e.,in the same direction as the anterior leaflet. The posterior leaflet motion closely follows the anterior leaflet pattern (Fig.9, panel a). In type 2 the initial movement of the posterior leaflet is in a direction opposite to that of the anterior leaflet, and the leaflet remains in a posterior position throughout diastole (Fig.9, panel b). In type 3 there is an early diastolic posterior motion of the posterior leaflet, followed by abnormal anterior motion (Fig.9, panel c). A type 3 motion pattern was considered to be present also in cases with alternating type 1 and 3 motion patterns of the posterior mitral leaflet.

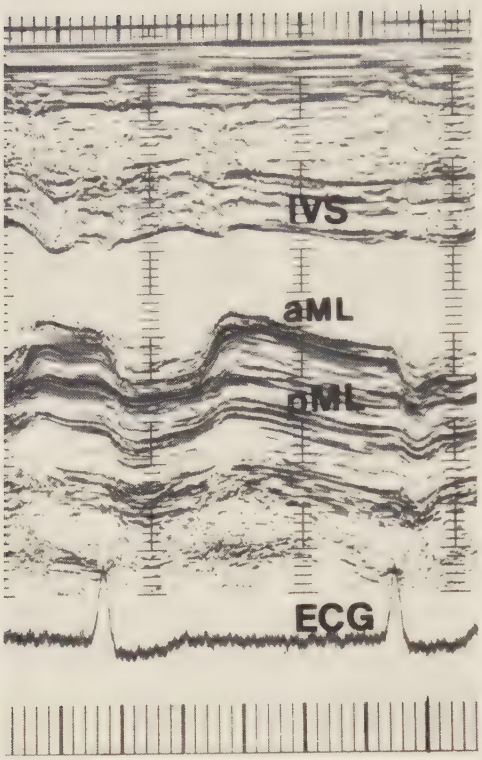


Fig. 9: Panel a.

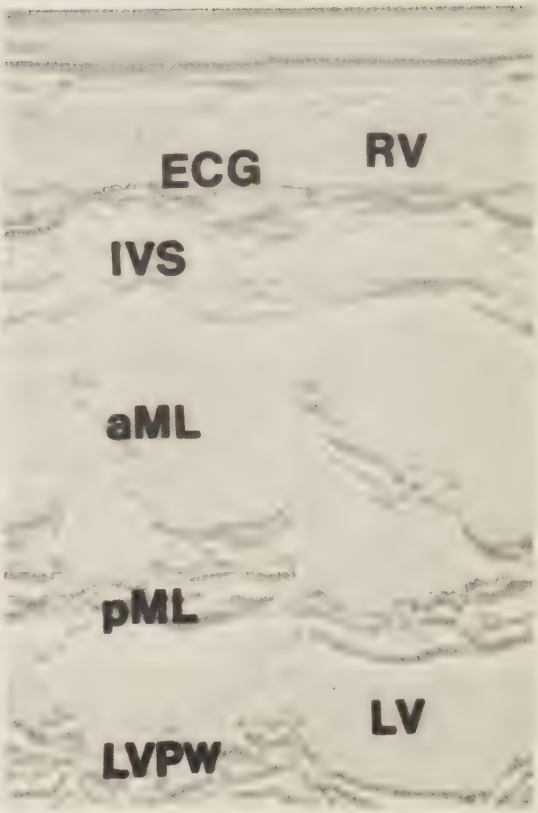


Fig. 9: Panel b.

Echocardiograms of mitral stenosis.

Panel a: The posterior mitral leaflet moves anterior and parallell to the anterior mitral leaflet in diastole (motion pattern type 1).

Panel b: The posterior mitral leaflet moves away from the anterior mitral leaflet (motion pattern type 2).

Panel c (next side): The posterior mitral leaflet makes a posterior movement early in diastole, followed by abnormal anterior movement (motion pattern type 3).

Panels a. and c. are recorded from the same patient.

aML = anterior mitral leaflet; pML = posterior mitral leaflet; RV = right ventricle; LV = left ventricle; IVS = intraventricular septum; LVPW = left ventricular posterior wall; ECG = electrocardiogram.

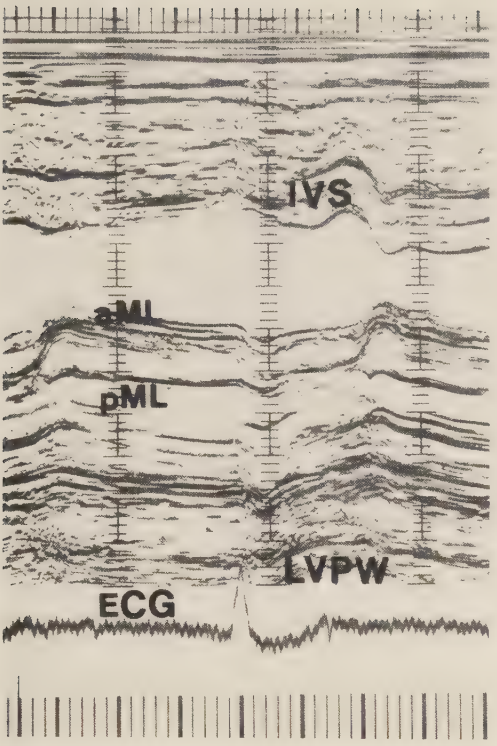


Fig. 9: Panel c.

A late postoperative echocardiographic study with identification of the posterior mitral leaflet was performed in 107 patients, at an average of 13.6±1.7 years after surgery, either at the late follow-up investigation or at previous examinations at least 10 years after the commissurotomy, with a range from 10.1 to 15.8 years. A second closed commissurotomy had been performed in three patients, at one, seven, and eight years before the study, respectively. Some preoperative characteristics of these patients are shown in Table I.

A cinefluorographic examination was performed in 101 of the 107 patients, and the relationship between the posterior mitral leaflet motion pattern and the occurrence of mitral valve calcification was evaluated in these patients.

g. Evaluation of left atrial size

The left atrial size was assessed by echocardiography. The echocardiograms were obtained with the patient in recumbent position. Left atrial dimension, assessed at the level of the aortic valves in early diastole, was measured as the greatest vertical distance between the posterior aortic wall and the posterior left atrial wall, including the thickness of the posterior wall of the aorta (Fig.10).

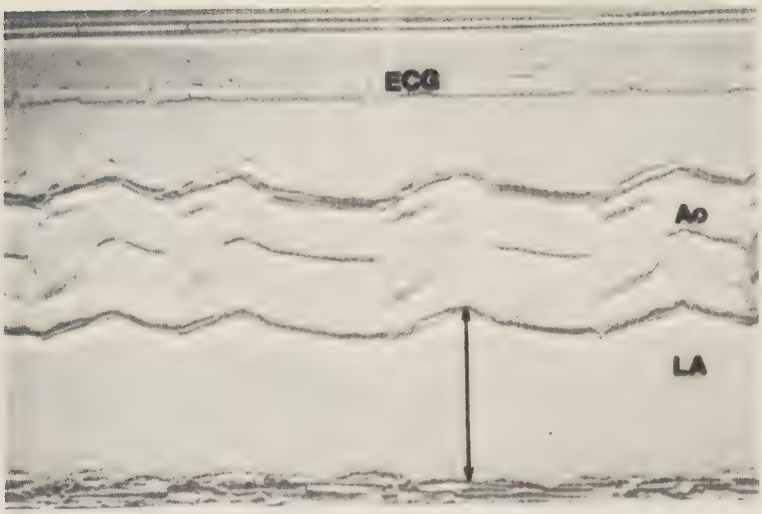


Fig. 10: Echocardiogram of the aorta (Ao) and left atrium (LA) with measurement of left atrial dimension.

A late postoperative echocardiographic study with assessment of left atrial size was performed in 109 patients at an average of 13.6±1.7 years after surgery, either at the late follow-up investigation or at previous examinations at least 10 years after the commissurotomy, with a range from 10.1 to 15.8 years. A second closed commissurotomy had been performed in three patients, at one, seven, and eight years before the study, respectively. Some preoperative characteristics of the patients are shown in Table I (page 13).

At the follow-up investigation the patients' past history of arrhythmias was obtained, and the clinical record of each patient was reviewed. Patients were subdivided into one of three groups: 1) stable sinus rhythm (Group 1, n=28); 2) intermittent episodes of atrial fibrillation, terminated either spontaneously or by antiarrhythmic agents or D.C. cardioversion (Group 2, n=13); 3) established atrial fibrillation (Group 3, n=68). Three patients with well documented long-standing atrial fibrillation, terminated by the spontaneous return of 'late' sinus rhythm (as described on page 41), were included in Group 3. Another three patients with pacemakers implanted because of bradyarrhythmia, preceded by long-standing atrial fibrillation,

were also included in this group. In all patients with chronic atrial fibrillation, the duration of the arrhythmia was also sought.

V. STATISTICAL METHODS

Student's t-test was used for comparison of the means from two different groups of patients. When there were more than two different groups of patients to compare, a one-way analysis of variance (ANOVA) was generally performed prior to making t-tests between pairs of groups. Student's t-test for paired data was used to compare the means from two different assessments within the same patients. Reported p-values from all versions of the t-test always refer to a two-sided alternative hypothesis.

The chi-square (χ^2) test with Yates' correction was employed for comparison of proportions in two independent samples.

The standard deviation (SD) was generally used as a measure of variation and appears in the text, together with the mean, as mean$\pm$SD.

Conventional probability levels of significance were used as follows:

$0.01 < p < 0.05$	probably significant	(x)
$0.001 < p < 0.01$	significant	(xx)
$p < 0.001$	highly significant	(xxx)

VI. METHODOLOGICAL CONSIDERATIONS.

a. Clinical implications of a reduced E-F slope

A reduced rate of the anterior mitral leaflet closure (E-F slope) is the classic criterion for the echocardiographic diagnosis of mitral stenosis (24). The relationship between the E-F slope and the mitral valve area assessed at cardiac catheterization and surgery was described in several reports from the 1960's (26,51,70,122,142,144). It was concluded that the echocardiogram from the anterior mitral leaflet was useful in estimating the degree of mitral stenosis as well as the degree of rigidity in the mitral valve (26). It was subsequently found, however, that the E-F slope

was reduced in several situations other than mitral stenosis, including primary pulmonary hypertension, aortic regurgitation, and conditions that decrease left ventricular compliance (45,90,113,124). The E-F slope is thus probably determined not only by changes in the valvular structures but also by a combination of other factors affecting mitral valve flow, e.g., cardiac output and filling characteristics of the left ventricle (18,111).

Although the echocardiogram is a reliable method of diagnosing mitral stenosis (18,111), the relation between echocardiographic measurements and the degree of narrowing of the mitral orifice has been reevaluated during recent years. Mary et al. (87) were thus unable to find any close correlation between mitral valve orifice estimated at surgery and either amplitude or diastolic E-F slope of the anterior leaflet. In a reassessment of the echocardiogram in mitral stenosis, Cope et al. (18) also concluded that the E-F slope is an unreliable index of the severity of the lesion and that measurement of the D-E amplitude is of little value in predicting which patients are suitable for mitral commissurotomy.

In the study by Cope et al. (18), the distribution of mitral valve area recording to E-F slope in patients with mitral stenosis was summarized from their own series and several previous reports. In patients with E-F slopes <15 mm/sec, 75% had severe mitral stenosis, i.e., a mitral valve area <1.3 cm^2. Among patients with E-F slopes >35 mm/sec, 14% had severe mitral stenosis. There was in general an approximate relationship between the severity of the stenosis and reduction of the E-F slope, although it was found that reliable predictions of valve area based on the echocardiogram were hazardous in an individual patient. It might be argued, however, that in a group of patients the use of the E-F slope for estimating the severity of the lesion might be justified. For example, in a group of patients with E-F slopes ≥40 mm/sec, there are very few with a severe mitral stenosis, and most patients with E-F slopes ≤20 mm/sec will probably have a severe stenosis. In the follow-up of an individual case, a rapid reduction of the E-F slope within a couple of years after commissurotomy will most likely be due to structural changes in the mitral valve. It therefore seems justified to use the E-F slope in estimating the incidence of mitral restenosis in the present follow-up study after commissurotomy.

It is realized that the definition of restenosis as an E-F slope ≤20 mm/sec, as used in the present study, is arbitrary and that a more flexible definition which takes into account the influences of age and other factors is preferable in clinical practise.

b. Clinical use of D-E amplitude

Echocardiography has also been used to judge the pliability of the mitral valve and hence the suitability of the valve for commissurotomy (26,33, 69). The pliability of the valve can be estimated by judging the total amplitude of motion of the anterior mitral leaflet. Originally, the amplitude of excursion of the anterior leaflet was measured from C to E (26,51,69) (Fig.6, page 24). During recent years the use of the D-E amplitude rather than the C-E amplitude has been recommended (118). As a rule, a mitral valve with a D-E amplitude of 20 mm or more is usually considered pliable (33).

c. Recording technique of the anterior mitral leaflet motion

There is no general recommendation regarding the number of heart cycles which should be measured to determine the E-F slope or D-E amplitude. Most authors of echocardiographic reports do not offer any information about the number of heart cycles that were used for the calculation of these variables. Gustafson (51) found that determination of the mean value of 10 and five heart cycles was sufficient for the calculation of the E-F slope and total amplitude, respectively. A more limited number of heart cycles has been used for the E-F determination in the present study, mainly because of its retrospective nature. However, in 2/3 of the echocardiograms, the mean E-F slope was calculated from five or more consecutive heart cycles. In many of the early echocardiograms in the present study, the D point was not easily identified. The D-E amplitude was therefore determined from only one heart cycle.

The influence of heart rhythm and rate on the anterior mitral leaflet motion has also been evaluated by Gustafson (51), who noted that the E-F slope showed no correlation to the length of the heart cycle in atrial fibrillation or to the heart rate in sinus rhythm. He also found

that a change of heart rhythm from atrial fibrillation to sinus rhythm did not have any significant effect on the E-F slope.

The present study was based on a review of echocardiograms recorded during a time span of 10-15 years. All echocardiographic recordings from the 1960's and almost all recordings from the first half of the 1970's were made by either Dr Inge Edler or Dr Arne Gustafson. The echocardiographic examinations at the late follow-up study were performed by the author. The vast majority of the echocardiograms in the present study have thus been recorded by a total of three different persons, all using an identical recording technique.

RESULTS AND DISCUSSION

I. EARLY AND LATE CLINICAL RESULTS OF MITRAL COMMISSUROTOMY

a. Results

1. Perioperative mortality

Five patients (3.4%) died in the perioperative period. Their mean age was 53.4 years, and only one patient was under 50 years of age. The perioperative mortality in patients over the age of 50 was thus 6.3%, as compared to 1.2% in patients below the age of 50. In patients with atrial fibrillation the perioperative mortality was 6.9% (4/58), as compared to 1.1% (1/90) in patients with sinus rhythm.

A preoperative cinefluorography had been performed in three of the five patients; it showed mitral valvular calcification in one. In one patient without calcification the cause of death was a cerebral embolus. Another patient died from myocardial infarction. The main cause of death in the remaining three patients was heart failure, complicated by renal failure in one case and respiratory failure in another.

2. Late mortality

Of 143 patients surviving commissurotomy, 20 died within the first decade after surgery. The principal cause of death was cardiac disease, as shown in Table II. Three of the deceased patients had been reoperated (Fig.11). One of these died 5 months after a second closed commissurotomy, and the other two died one month and 8 years, respectively, after prosthetic mitral valve replacement.

Table II: Causes of death within the first decade after mitral commissurotomy (n=25).

	No. of patients
Perioperative	5
Perioperative at second operation	1
Heart failure	10
Sudden death Myocardial infarction	4
Cerebral embolism	2
Cerebral haemorrhage	1
Renal failure	1
Malignant disease	1
Total	25

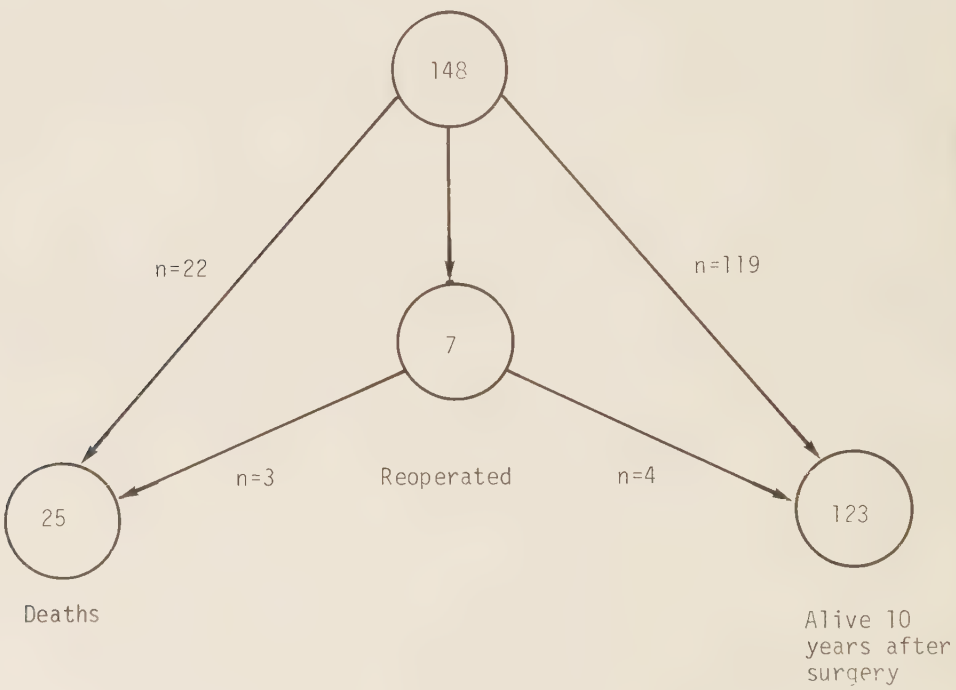


Fig. 11: Status 10 years after surgery of patients who underwent closed commissurotomy between May 1963 and the end of December 1968 (n=148).

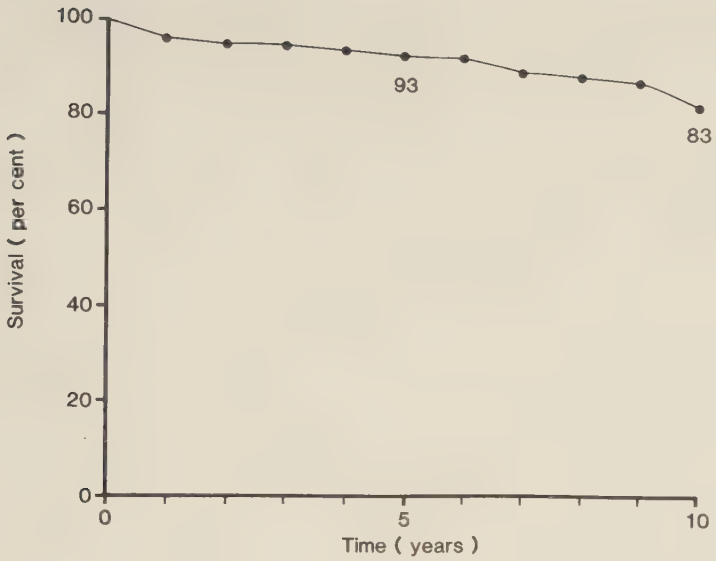


Fig. 12: Survival curve after closed commissurotomy (n=148).

The survival curve for the first 10 years after commissurotomy is shown in Fig. 12. The survival percentage was 93% after five years and 83% after 10 years. The ten-year survival percentage for patients with atrial fibrillation was 78%, as compared to 87% for patients in sinus rhythm at the time of surgery (Table III). In patients with a preoperative finding of valvular calcification, the ten-year survival percentage was 78% and, in those over the age of 50 (at surgery), 76%. An identical ten-year survival (76%) was seen in patients with palpable mitral regurgitation (Table III).

Table III: Some preoperative factors involved in 10-year survival after closed commissurotomy.

Factor	No. of patients	Alive	
		No.	%
Age (years)			
<50	85	75	88
≥50	63	48	76
Heart rhythm			
Sinus rhythm	90	78	87
Atrial fibrillation	58	45	78
Valve status			
No valvular calcification	106	93	88
Valvular calcification	36	28	78
No mitral regurg. at surgery	85	75	88
Mitral regurg. at surgery	63	48	76

3. Reoperations

Seven patients were reoperated within the first decade after commissurotomy (Fig.11), i.e., 4.9% of those surviving the initial surgery. The secondary surgical procedures included second closed commissurotomy (three patients), prosthetic mitral valve replacement (two patients), prosthetic aortic and mitral valve replacement (one patient), and closure of a cleft in the anterior mitral leaflet caused by surgery (one patient).

4. Heart rhythm

The preoperative incidence of atrial fibrillation in those 123 patients surviving surgery for more than ten years was 37% (Table IV). At follow-up, 72 patients had atrial fibrillation (Table IV). A pacemaker implanta-

Table IV: Heart rhythm preoperatively and 10-15 years postoperatively (mean 13.4±1.7 years, range 10.1 to 15.8 years) in patients surviving commissurotomy ≥10 years (n=123).

Heart rhythm	No. of patients	
	Preoperative	10-15 years after surgery
Sinus rhythm	70	29
Intermittent atrial fibrillation	8	13
Atrial fibrillation	45	72
Pacemaker	0	5
Nodal rhythm	0	1
Late sinus rhythm	0	3

tion had been performed in five patients because of bradyarrhythmia. A long history of atrial fibrillation was found in the majority of these patients as well as in the patient with nodal rhythm at the follow-up study. In thirteen patients intermittent episodes of atrial fibrillation were found, terminated spontaneously, by antiarrhythmic agents, or by D.C. cardioversion. Twenty-nine patients had had a stable sinus rhythm throughout the years. In three patients sinus rhythm spontaneously returned after a period of continuous atrial fibrillation for four, eight, and thirteen years, respectively. The sinus rhythm was in these cases unstable, alternating with episodes of atrial tachycardia and/or atrial fibrillation. These patients are referred to as the "late sinus rhythm" group in Table IV. Two of the patients with late sinus rhythm showed first degree AV-block when in sinus rhythm.

On subsequent controls after the follow-up study, two additional patients exhibited spontaneous return of sinus rhythm. One man with continuous atrial fibrillation for 21 years reverted to sinus rhythm with first degree AV-block (P-Q 0.40 sec) at the age of 57. A third degree AV-block developed one year later. One woman with atrial fibrillation for 30 years spontaneously returned to sinus rhythm at the age of 68. The P wave was of low amplitude in both these patients. The return of sinus rhythm caused no change in the clinical state of the patients.

Continuous atrial fibrillation with a duration exceeding three postoperative years was found in 76 patients in the total patient series. The incidence of late sinus rhythm in this group of patients with long-lasting atrial fibrillation after commissurotomy was thus 6.6%.

5. Mitral regurgitation

α) Immediately postoperative.
A moderate or severe mitral regurgitation was caused by surgery in five patients, as noted by the surgeon after the dilatation of the valve. One patient had a closure of a cleft in the anterior mitral leaflet performed four months later with a good long-term result. One patient with a ruptured chorda tendinae died from cardiac failure eight years after surgery. Mitral valve replacement was performed in one patient one year after the commissurotomy. Another patient with a severe mitral regurgitation caused by surgery died six months later because of cerebral embolism. Only one patient survived the follow-up period without a second heart operation. Fifteen years after the commissurotomy she was in function class III B, with signs of severe mitral as well as tricuspid regurgitation.

β) At late follow-up.
Ten years after surgery there were 119 single operated patients still alive (Fig.11). An assessment of the presence or absence of mitral regurgitation was performed in 109 of these patients 10-15 years after surgery, using either invasive (22 cases) or non-invasive (87 cases) methods (Table V), as previously described (cf. p.17). Signs of mitral regurgitation were found in 74% of the patients, as compared to the preoperative finding of mitral regurgitation in 39% in the same patient-group.

In two patients cineangiography was performed in another hospital. A comparison between the results obtained by the invasive and non-invasive methods was made in the remaining 20 patients (Table VI). A good correlation between the results obtained by the two methods was found in 15 patients, and no major discrepancies were noted in the classification of the remaining five patients.

Table V: Incidence of mitral regurgitation 10-15 years after commissurotomy (n=109), as assessed by invasive or non-invasive methods.

Mitral regurgitation	Method of assessment		Total
	Angiocardiography	Heart auscultation	
0	4	24	28
+	4	36	40
++	8	27	41
+++	6		
Total	22	87	109

Table VI: Correlation between cineangiographic and non-invasive identification of mitral regurgitation (n=20).

Grading of mitral regurgitation: 0 = none; + = light; ++/+++ = moderate to severe.

Cineangiography	Heart auscultation			Total
	0	+	++/+++	
0	2	2	0	4
+	0	0	3	3
++/+++	0	0	13	13
Total	2	2	16	20

6. Aortic valve disease

Evidence of aortic regurgitation and/or aortic stenosis was found in 14 of 23 invasively studied patients. By non-invasive methods signs of aortic valve disease were found in 35 of the remaining 89 patients. The incidence of aortic valve disease was thus 44%, as estimated in 112 of 122 patients who survived commissurotomy for more than 10 years without aor-

tic valve replacement. Before surgery, it was 31% in this group of patients.

7. Tricuspid regurgitation

The results 10-15 years after surgery of liver and jugular venous pulse curve analysis (performed in 98 single operated patients) are summarized in Table VII. Non-invasive signs of tricuspid regurgitation were found in 16 patients (16%). A ventricularization of the pulse curves (Type 1) was found in seven patients. A pulse wave contour of Type 2, i.e., an abbreviated x-descent followed by a regurgitant wave in late systole, exceeding the v-wave or merging with it, was found in nine patients. Most of these patients had atrial fibrillation, and pacemakers had been implanted in three of them. Cinefluorography of the heart revealed mitral valve calcification in all patients but one; this patient had a severe mitral regurgitation caused by surgery 15 years before the follow-up investigation.

Table VII: Tricuspid regurgitation 10-15 years after commissurotomy related to heart rhythm and mitral valvular calcification (as evaluated by cinefluorography).

Pulse wave contour Type 1: Normal x-descent completely obliterated and replaced by large systolic wave. Type 2: Abbreviated x-descent followed by regurgitant wave in late systole, exceeding the v-wave or merging with it. AF=atrial fibrillation. NR=nodal rhythm. PM=pacemaker.

Tricuspid regurgitation	No. of patients	Heart rhythm			Mitral valve calcification		
		AF	NR	PM	Yes	No	Unknown
Pulse wave contour Type 1	7	4	1	2	6	1	0
Pulse wave contour Type 2	9	8	0	1	8	0	1
Total	16	12	1	3	14	1	1

A second heart operation with mitral valve replacement was performed in three of these patients within 16 months after the follow-up study. One patient had a pulse wave contour of Type 1 and the other two of Type 2. The diagnosis of tricuspid regurgitation was confirmed at surgery, leading to tricuspid annuloplasty in all three patients.

3. Systemic embolism

Nineteen episodes diagnosed as presumed systemic emboli occurred in 18 patients (13%) during the follow-up period. The overall incidence of systemic embolism was 1.1% per patient-year. The sites of emboli were cerebral in 17 cases, peripheral (limb) in one, and visceral (kidney) in one. Cerebral emboli, occurring 6 months and 4 years after surgery, respectively, were the cause of death in two patients. During the first post-operative year, the incidence of embolism was 2.1%, but in several cases (n=8) embolization occurred after more than 10 years after surgery (Table VIII).

Table VIII: Systemic embolism related to time after commissurotomy.

	Interval between surgery and embolism (years)			
	<1	1-5	6-10	>10
No. of embolic episodes	3	4	4	8

The relation between embolization and heart rhythm is shown in Table IX. Only two of nineteen embolic episodes occurred in patients with regular sinus rhythm, and these two patients developed continuous atrial fibrillation one and seven years, respectively, after the embolic event. Four patients gave a history of paroxysmal atrial fibrillation, and an intermittent arrhythmia at the time of embolization was documented in three of these cases. Atrial fibrillation was recognized for the first time at the embolic event in three patients, and the time of onset of the arrhythmia could not be ascertained. Ten embolic episodes occurred in patients in whom it was possible to ascertain the time of onset of atrial fibrillation with reasonable accuracy. In one of these patients emboliza-

Table IX: Systemic embolism related to heart rhythm.

	Sinus rhythm	Intermittent atrial fibrillation	Atrial fibrillation (years)			
			<2	2-5	>5	Unknown
No. of embolic episodes	2	4	5	2	3	3

tion occurred two days after D.C. cardioversion (one year after commissurotomy).

Anticoagulant treatment at the time of the embolic event had not been given to any embolic patient with sinus rhythm, intermittent atrial fibrillation, or unknown atrial fibrillation. The remaining ten episodes of systemic emboli occurred in patients with established atrial fibrillation. No anticoagulant treatment was given in four of these cases, and in another two cases, including the patient with embolization after D.C. cardioversion, the prothrombin level was considerably outside the accepted therapeutic range at the time of the embolus. In three cases it could not be ascertained whether or not the patient was on anticoagulant therapy at the time of embolization. One patient was treated with anticoagulants, but the prothrombin level at the time of embolization is not known.

Most patients with atrial fibrillation and all but one patient with paroxysmal arrhythmia and a history of embolization were treated with anticoagulants. The minor complications resulting from this treatment were not recorded. There was, however, one death probably caused by anticoagulant therapy. This patient was a 66-year-old woman with continuous atrial fibrillation and a previous history of cerebral embolism, who died from cerebral haemorrhage. She had a low prothrombin level (<5%) when admitted to the hospital.

9. Clinical disability

Before surgery, a uniform functional classification was performed in the

Table X: Functional classification (NYHA) at 15-year follow-up compared to preoperative status (n=45).

Preoperative class		Postoperative class				
Function class	No. of patients	I	II	IIIA	IIIB	IV
I	3	1	1	1	0	0
II	16	3	5	6	1	1
IIIA	19	5	2	8	4	0
IIIB	7	0	0	6	1	0
Total	45	9	8	21	6	1

first 67 patients in the present series. A reclassification 15 years after surgery was possible in 45 patients who had not undergone any secondary procedure to the mitral valve (Table X). It is noteworthy that five of these patients who, before surgery, were in function class III A now belonged to function class I.

The results of the functional classification at the late follow-up study, performed in 92 patients, are shown in Table XI. Functional classes I-II were found in 42% of the patients, and 18% had no subjective cardiac symptoms at all. Reduced function at the follow-up investigation was not always caused by mitral valve disease. Aortic valve disease or coronary heart disease was probably the main limiting factor in some cases.

Table XI: Functional classification (NYHA) 10-15 years after commissurotomy (n=92).

Function class	No. of patients	%
I	17	18
II	22	24
IIIA	41	45
IIIB	11	12
IV	1	1
Total	92	100

10. Overall clinical results in relation to some preoperative characteristics

A clinically satisfactory result was recorded in 27% (39/143) of those patients surviving the initial commissurotomy. These patients were in functional class I or II at the late follow-up study without any secondary procedure applied to the mitral valve (Group A). Unsatisfactory results were found in 63% (90/143, Group B). These included: 1) patients in functional class III or IV at the 10-15 year follow-up study (n=53); 2) patients having undergone secondary procedure to the mitral valve (n=17); and 3) deceased patients (single operated), not including non-cardiac deaths (n=20).

In the remaining 14 patients (10%), the results of surgery were not classified into satisfactory or unsatisfactory. The reasons for this were: 1) non-cardiac deaths during follow-up (n=8); 2) functional classification according to NYHA not performed at late follow-up due to non-cardiac disease (n=3); and 3) follow-up study missing (n=3).

Some preoperative findings in the two different groups of patients are summarized in Table XII. Patients with unsatisfactory results (Group B) were older ($p < 0.001$) than those with satisfactory results (Group A). Other factors than age that were related to unsatisfactory results were

Table XII: Some preoperative data in patients with satisfactory (Group A) and unsatisfactory (Group B) long-term clinical results after closed commissurotomy.

AF = atrial fibrillation; MR = mitral regurgitation; AVD = aortic valve disease; Calc. = mitral valvular calcification (as evaluated by cine-fluorography). xxx = $p < 0.001$.

Group (no. of patients)	Age (mean±SD) Years	Females %	AF %	MR %	AVD %	Calc. %
A (39)	42.0 ±8.3 | xxx |	56	13	26	23	10
B (90)	48.8 ±7.6	71	49	53	39	32

mitral valve calcification, atrial fibrillation, mitral regurgitation and coexisting aortic valve disease.

b) Discussion

1. Early and late mortality

The *perioperative mortality* in the present study (3.4%) is in accordance with previous reports on the early results of closed commissurotomy. Thus, several investigators reported a perioperative mortality between 1.5 and 4% in patients operated on during the 1960's (38,47,73,137). A perioperative mortality between 5 and 10% was a common finding in patient series from the 1950's and early 1960's (38,48,71,72,73,82), but a substantial decrease in this figure was noted towards the end of this period (43).

A *5-year survival percentage* of 93% was found in this study, in accordance with other reports on the results of commissurotomy performed during the mid-1960's (38,47,137). A considerably lower 5-year survival (80-85%) was generally found in series including patients operated on in the 1950's (38,71,73,95,100).

Also the *10-year survival percentage* of 83% in the present study compares favourably with the results obtained in earlier series from the 1950's (60-70%) (71,73,95,100), and is in accordance with other reports on the late results of closed commissurotomy performed during the 1960's (38, 121). Factors related to a moderately reduced long-term survival in the present study were age >50 years and the presence of atrial fibrillation, mitral valve calcification and mitral regurgitation.

Heavy calcification of the mitral valve has frequently been reported to result in a bad prognosis after commissurotomy (31,47,71,74,100).

In patients with moderate to severe mitral regurgitation, the results of closed commissurotomy have been found to be poor (47), but minor amounts of regurgitation do not seem to seriously affect the patient's course (43). In the present series a regurgitant jet was a common finding at commissurotomy, but there were probably only minor regurgitation in most patients (cf. p. 14).

Although it has previously been reported that advanced age has no obvious effect on results of commissurotomy (47,75), elderly patients have an increased incidence of complicating factors such as atrial fibrillation, diabetes mellitus, coronary heart disease, and hypertension (47). On the other hand, the mortality rate in patients over the age of 50 has been found to be significantly lower after commissurotomy than in medically treated patients throughout a follow-up period of 15 years (128).

2. Reoperations

The *reoperation rate* within the first decade after commissurotomy was 4.9% in the present series. This is low in comparison with other studies, in which a reoperation rate between 6.7 and 34% has been reported at an average of 4.4 to 10 years after surgery (31,47,73,83,95,100,121). At the time of the follow-up study (13.8 years after surgery), the reoperation rate had increased to 11.9% (17/143; p. 15). However, within 18 months after the present follow-up - and in part due to it - an additional 15 patients had a second heart operation, probably indicating a too low reoperation rate in the past.

3. Heart rhythm

α) Atrial fibrillation.

In many previous studies, as in the present one, the incidence of atrial fibrillation at the time of mitral commissurotomy has been about 40% (46,66,83,105,146). The preoperative incidence of atrial fibrillation appears to be related to the mean age of the patients. For example, in a series reported by Mc.C. Boyle (89), only 27% of the patients (mean age, 33.8 years) had atrial fibrillation at the time of surgery, as compared to 61% in another series (mean age, 49 years) reported by Örndahl et al. (104).

A relationship between atrial fibrillation and decreased short- and long-term survival after closed commissurotomy was found in the present study, although the higher mean age among patients with atrial fibrillation makes it difficult to determine whether the poorer result in these cases was the result of age or the arrhythmia. Other investigators have also found that atrial fibrillation increases the risk of operation and makes the long- and short-term prognosis worse (74,83,104,133). In a hemodynamic follow-up study after mitral commissurotomy, Feigenbaum et al. (34) recorded poorer results in patients with atrial fibrillation than in those in sinus rhythm. The increase in mitral valve area and the decreases in left atrial and pulmonary artery pressures were thus significantly less in patients with atrial fibrillation than in patients in sinus rhythm.

β) Late sinus rhythm.

Five patients with late sinus rhythm could be identified in the present limited series of patients with long-lasting atrial fibrillation after previous mitral commissurotomy. Late sinus rhythm was thereby recorded in 6.6% of all patients with continuous atrial fibrillation during a minimum of three postoperative years.

The occurrence of late sinus rhythm has previously been documented only in a limited number of case reports. After the first report by Burch in 1939 (14), an additional 21 cases of spontaneous reversion from atrial fibrillation to sinus rhythm were described in the literature up to 1979. A review of these cases, as well as a report of 23 additional cases of late sinus rhythm, was recently published by Olsson et al. (103). Of all 45 cases, 39 had signs of mitral valve disease. In the majority of these

patients the electrocardiogram showed first degree AV-block after return to sinus rhythm and a low-amplitude P-wave, as if left atrial P component was lacking. During the course of late sinus rhythm, several patients exhibited episodes of atrial tachycardia with AV-block, as well as episodes of atrial fibrillation, which is consistent with the findings in the present study.

A pathophysiological mechanism for the appearance of late sinus rhythm has also been proposed by Olsson et al. (103). The authors found electrical, mechanical and histopathological evidence that the left atrial muscle is inactive during late sinus rhythm in patients with mitral valve disease. With deterioration of left atrial muscle, the electrophysiological factors responsible for maintenance of atrial fibrillation might have disappeared, thereby allowing sinus rhythm to be re-established.

The results of the present study give support to the statement made by Olsson et al. (103) that the appearance of late sinus rhythm is a far more common phenomenon than suggested up to now.

4. Mitral regurgitation

An apical systolic murmur was found in 74% of the patients in the present post-operative follow-up study. A loud pansystolic murmur at the apex of the heart is probably in most cases due to mitral regurgitation. It has been found, however, that the interpretation of the physical examination is often misleading in patients with a previous history of mitral commissurotomy (54). Some patients with severe regurgitation may have a relatively quiet murmur, or occasionally none, and sometimes a loud murmur signifies relatively mild regurgitation (138).

In the present study, a comparison between the cineangiographic and clinical assessment of mitral regurgitation showed a good correlation between these methods. The comparison study was, however, performed in a subsample of patients and mainly in those in whom severe mitral regurgitation was suspected. The findings may therefore not be quite representative for the whole series.

5. Aortic valve disease

Signs of aortic valve disease were found in 44% of the patients 10-15 years after surgery. Coexisting aortic valve disease is probably diagnosed with greater accuracy by physical examination than is mitral regurgitation in patients with mitral stenosis. The absence of a diastolic murmur along the left sternal border thus usually excludes the existence of severe aortic regurgitation (17,108).

Aortic valve involvement was diagnosed preoperatively in 30% of all patients in the present study, in accordance with several previous reports (17,71,85,137). The incidence of aortic valve disease increased by 13% during follow-up, indicating that, the longer the patients are observed, the more cases will also develop signs of aortic valve disease. A similar conclusion has previously been drawn by Werkö (141), who found that about 10% of patients with mitral stenosis "acquired" aortic valve involvement in 5-10 years of observation.

As a result of the follow-up, an aortic valve replacement was performed in four patients within one year after the study. The main indication for surgery in these patients - as well as in those two who had aortic valve replacement performed before follow-up - was severe aortic regurgitation. A progressive aortic regurgitation might thus contribute to unsatisfactory long-term results after commissurotomy, although the aortic valve disease probably was of minor importance in most cases in the present series. The presence of associated aortic valve disease has not always been found to have a significant effect on the results of commissurotomy in previous studies (30,83). The post-operative observation time has, however, then been limited to 5-6 years.

6. Tricuspid regurgitation

Non-invasive signs of tricuspid regurgitation were found in 16 patients at follow-up. These patients were all clinically seriously disabled from their heart disease; they were either in functional class III A or III B. Mitral valve calcification was present in 14 patients, indicating an underlying advanced mitral valve disease.

The use of venous pulse curves as a tool for diagnosing tricuspid regur-

gitation has a long tradition (22,93). It is based on the assumption that pulsations in the central veins are produced by right atrial and ventricular activity (63). Phlebographic tracings from the internal jugular vein thus closely reflect the wave form of the right atrial pulse (93).

The significance of right atrial pressure contour has, however, been seriously questioned. A normal right atrial pressure curve has thus been noted in several patients with tricuspid regurgitation, diagnosed either at surgery or by cineangiocardiography (15,116). It has been pointed out that the amplitude and shape of the right atrial pressure curve depend not only upon the severity of the tricuspid regurgitation but also on right atrial size, wall compliance, average pressure level, and right ventricular systolic pressure (107).

The Type 1 pressure contour (Fig.3, p. 19), which was seen in seven patients in the present study, has been considered typical for a marked degree of tricuspid regurgitation (63). This pattern of ventricularization of right atrial pressure pulse has been found to be fairly specific for tricuspid regurgitation (15,80), although occasional false positives have been found in the presence of right ventricular failure (15). The significance of Type 2 pressure contour (Fig.4, p. 20) is not well known. In the present study, however, two patients with this type of venous pulse curve had the diagnosis of tricuspid regurgitation verified at subsequent open heart surgery. Although the number of false negatives is unknown, an analysis of venous pulse curves may be useful in defining a subgroup of patients with mitral valve disease, in whom associated significant tricuspid regurgitation is present.

An artificial pacemaker had been implanted in three of 16 patients with signs of tricuspid regurgitation at follow-up. Artifactual tricuspid regurgitation caused by pacemaker catheters cannot be completely ruled out (114), although general experience has shown that the presence of a cardiac catheter across a normal tricuspid valve probably does not induce valvular incompetence (107). Furthermore, in one of our patients the presence of tricuspid regurgitation was recognized more than 10 years before the pacemaker implantation.

7. Systemic embolism

Systemic embolism was diagnosed in 13% of our patients followed for 10-15 years after closed mitral commissurotomy. The incidence of emboli was 1.1% per patient-year. Ellis et al. (31) have reported a similar low incidence (1.1% per patient-year) of late systemic embolization in their 15-20-year follow-up study of 1.000 surgically treated patients with mitral stenosis. Lowther and Turner(83) found an incidence of 1.4% per patient-year in 185 patients followed for six years after commissurotomy. Unfortunately, no information about the use of anticoagulants was given in these reports.

In medically treated patients, a higher incidence of emboli has generally been recorded. Fleming and Bailey(36) thus found an incidence of embolism of 25% in 500 patients with mitral valve disease, followed for nearly one decade. Bannister (4) found systemic embolism in 21% of patients with moderate mitral stenosis followed for an average of four and a half years after deferment of commissurotomy. In these cases surgery had been deferred because symptoms were trivial or absent.

Only two of 19 embolic episodes in the present study occurred in patients with regular sinus rhythm, indicating a close relationship between atrial fibrillation and systemic embolism in patients with mitral valve disease. Other investigators have also found that atrial fibrillation is the main factor in the production of systemic embolism (19,132). Emboli might, however, occur even in young symptom-free patients in sinus rhythm with mild mitral valve disease (36).

The site of emboli was cerebral in 17 (out of 19) embolic episodes in the present series, confirming other reports of a disturbingly high rate of cerebral emboli in patients with mitral valve disease (36,132,146). The true incidence of systemic emboli is almost certainly higher than reported in this series as well as in others, as peripheral and visceral embolizations are notably difficult to diagnose clinically (31,36).

A favourable effect of continuous anticoagulant therapy on the incidence of embolic episodes in mitral valve disease has previously been noted (36). Long-term anticoagulation has also been found to have a protective effect against embolic recurrences (19,132). The only recurrent episode

of embolism in the present study occurred in a patient who was not treated with anticoagulants. The low rate of recurrence in this study is probably due to the use of long-term anticoagulant therapy in almost all patients with an embolic episode. At the time of the first embolic event, most patients in the present study were not treated with anticoagulants, or had a prothrombin level outside the therapeutic range. These findings further support the view that an adequate anticoagulant therapy is important in the prevention of systemic embolism in patients with mitral valve disease and atrial fibrillation.

8. Overall clinical results

In the present study 42% of the surviving patients were in function group I-II 10-15 years after commissurotomy without any secondary procedure applied to the mitral valve. This is in close agreement with, e.g., the findings by Keith and Fowler, who noted satisfactory results in 43% of the patients at an average of 11.9 years after surgery (71).

Mitral valve calcification, mitral regurgitation, atrial fibrillation and multivalvular disease were all factors which had an adverse effect on the long-term results after commissurotomy in the present study, as well as in others previously published (43,71). In some previous reports, the long-term results have been better in women than in men (71,95). This could, however, not be verified in this study.

Ellis et al. (31) have published the longest reported follow-up study of a large group of patients with mitral stenosis operated on by the closed technique. They noted an approximatively linear decrease in the percentage of patients who continue to remain improved at each follow-up year. The present study confirms, however, that long-lasting palliation is achieved by closed commissurotomy in a great number of patients with mitral stenosis.

II. PHYSICAL WORKING CAPACITY. A LONG-TERM FOLLOW-UP STUDY AFTER CLOSED COMMISSUROTOMY

a. Results

1. Preoperative evaluation

Before surgery, 44 males (mean age, 46.3±7.8 years) and 91 females (mean age, 47.3±8.5 years) performed a conclusive exercise test, revealing a mean PWC of 96.6±28.4 W and 48.1±20.6 W for males and females, respectively, and a mean PWC% of 41.0±16.5 for the entire series. Atrial fibrillation was present in 40% of the patients.

The mean preoperative PWC in those 65 patients performing a repeat exercise test 10-15 years after surgery was 109.4±27.5 W for males (n=22, mean age, 43.0±7.9 years) and 55.0±20.1 W for females (n=43, mean age, 42.8±7.3 years). The mean PWC% was 45.1±16.5. Atrial fibrillation was found in 26% of the patients.

2. Late postoperative evaluation

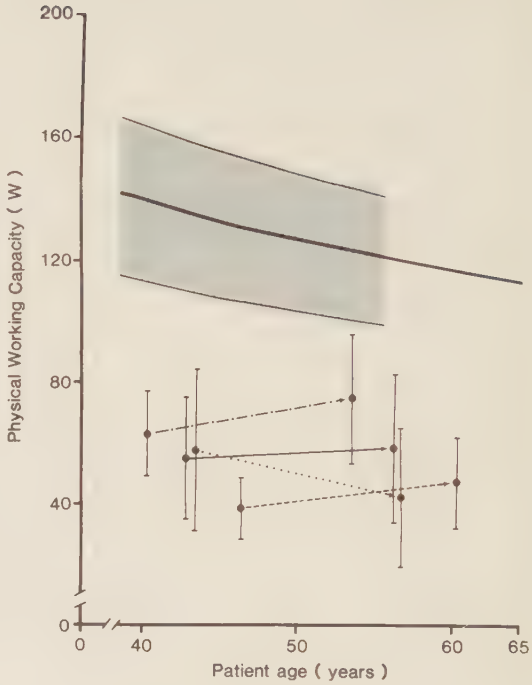
A small, but insignificant, increase in *mean PWC* was found in both sexes 10 - 15 years after surgery (as compared to preoperatively), with a mean PWC of 114.8±37.6 W and 58.2±24.8 W for males and females, respectively (Figs.13+14). Sinus rhythm was revealed in 49% of the patients at the follow-up study, as compared to 74% before surgery in the same group.

After dividing the selected patients with late follow-up study into different groups according to their heart rhythm, the results of the exercise tests were evaluated in the largest subgroups (n>10) (Figs.13+14). A small increase of mean PWC was found in patients with unchanged heart rhythm throughout the follow-up period (Group I, males and females; Group III, females), reaching statistical significance ($p<0.05$) only in females with sinus rhythm both pre- and postoperatively. A decrease in mean PWC ($p<0.05$) was noted in patients who had changed from sinus rhythm preoperatively to atrial fibrillation at the follow-up study (Group II, females).

Fig. 13: Mean (±SD) pre- and late postoperative PWC (W) as related to patient age (years) in the total series of *females* as well as in the different subgroups. Normal values (mean ±SD) according to Nordesjö (99) within shaded area.

SR = sinus rhythm; AF = atrial fibrillation.

——— Total series, n=43
-·-·- Group I (SR→SR), n=19
····· Group II (SR→AF), n=12
----- Group III (AF→AF), n=12



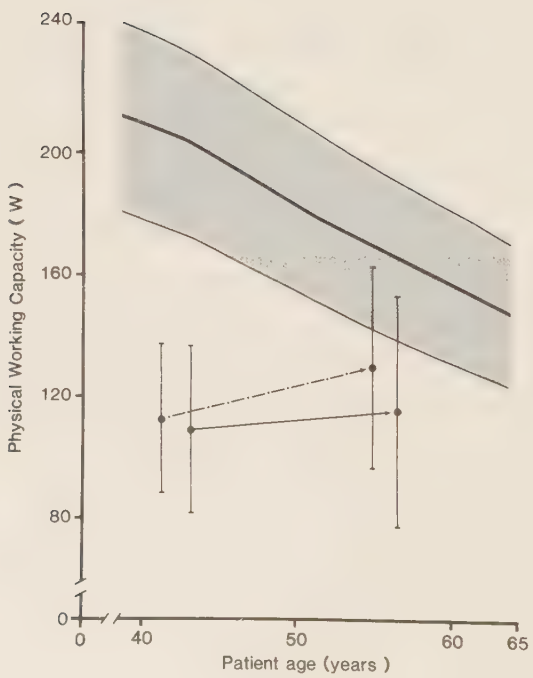


Fig. 14: Mean (±SD) pre- and late postoperative PWC (W) as related to patient age (years) in the total series of *males* as well as in the largest subgroup. Normal values (mean ±SD) according to Nordesjö (99) within shaded area.

SR = sinus rhythm.

——— Total series, n=22
-·-·-·- Group I (SR→SR), n=13

Mean PWC% increased from 45.1±16.5 to 54.9±22.1 at the late postoperative evaluation ($p<0.001$) (Table XIII). Also in PWC% there was an increase in patients with unchanged heart rhythm (Groups I+III) postoperatively as compared to preoperatively ($p<0.001$ and $p<0.01$, respectively), while in patients with changed heart rhythm (from sinus rhythm to atrial fibrillation, Group II) there was a minor decrease in PWC%.

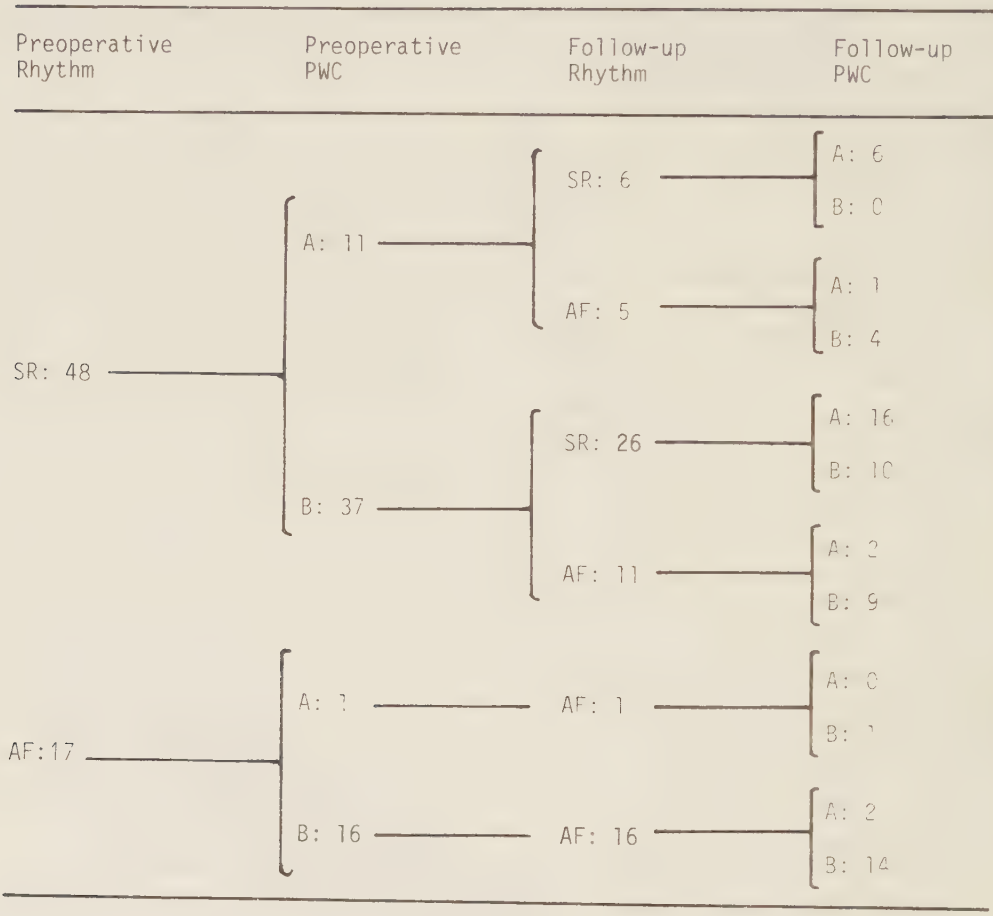
Table XIII: Mean (±SD) PWC% preoperatively and 10-15 years postoperatively in different groups of patients (n=65).

Group (no. of patients)	PWC% Preoperatively	10-15 years after surgery	Difference: preop. vs. postop.
I (32)	49.0±13.8	66.9±18.9	$p<0.001$
II (16)	49.0±19.9	43.4±23.5	N.S.
III (17)	34.1±13.4	43.2±13.3	$p<0.01$
Total (65)	45.1±16.5	54.9±22.1	$p<0.001$

In each group there were patients with low as well as normal or high PWC. In the evaluation of PWC, individual PWC values were also related to height, body weight and body constitution of the patients (99). If a good, normal or only slightly reduced PWC was regarded as a satisfactory result of the exercise test, 16% of the total series of patients (n=135) fulfilled this criterion preoperatively, as compared to 18% of the patients in the selected group with late postoperative evaluation (n=65) (Table XIV: Preop. PWC). A satisfactory result of the follow-up exercise test was seen in 42% of the patients in the selected group (n=65) (Table XIV: Follow-up PWC). Furthermore, when the exercise test, pre- and postoperatively, was related to heart rhythm, no less than 69% of patients with stable sinus rhythm throughout the follow-up period (Group I, n=32) had a good, normal or only slightly reduced PWC 10-15 years after commissurotomy.

Table XIV: Pre- and postoperative PWC related to heart rhythm. Figures denote number of patients in each group.

SR = sinus rhythm; AF = atrial fibrillation; A = satisfactory PWC; B = unsatisfactory PWC.



b. Discussion

Twenty-seven patients (42%) had a normal or near-normal PWC at the late follow-up evaluation. A satisfactory PWC 10-15 years after surgery was found in the majority of patients (69%) with stable sinus rhythm throughout the observation period, but also in some patients (15%) with atrial fibrillation. The results of the follow-up exercise tests were, furthermore, satisfactory in 20 of 53 patients with unsatisfactory PWC preoperatively, indicating sustained improvement in 38% of the patients.

In a previous evaluation of serial tests of exercise tolerance before and after commissurotomy, Logan et al. (81) found sustained improvement in no less than 73% of patients followed for 3-5 years after surgery. It is, however, difficult to compare the results of the two studies because of differences in methods of assessing exercise tolerance and in follow-up time.

Granath (46) found a significantly higher PWC at a mean time of 2.9 years after commissurotomy as compared to preoperatively in 32 patients with stable sinus rhythm, while no significant difference was found in patients with continuous atrial fibrillation. Although the follow-up period was extended for another 10 years in the present study, a significant increase in PWC ($p<0.05$) was still present in the female group of patients with sinus rhythm throughout the observation period.

The follow-up exercise test was possible to perform in 65 (58%) of the patients surviving surgery for one decade or more (and with no secondary procedure applied to the mitral valve). Thus it might be questioned whether the results are applicable to all patients alive 10-15 years after commissurotomy. The selected follow-up series (n=65) differed preoperatively from the total group of survivors mainly in two respects: a lower mean age and a higher occurrence of sinus rhythm. Sinus rhythm was present in 49% of the patients at the follow-up exercise test, as compared to only 34% of the entire group of 123 patients surviving surgery for 10 years. The influence of age difference may be eliminated by estimating the PWC%, while the difference in heart rhythm might indicate a favourable higher mean PWC in the selected subsample.

In the present study, both patient groups with unchanged heart rhythm (Groups I+III) showed an increase in mean PWC% ($p<0.001$ and $p<0.01$, respectively) at follow-up. An improvement in cardiac output (20,41) and in exercise performance (41) has been shown after conversion to sinus rhythm in patients with atrial fibrillation and mitral stenosis. Conversely, a change of rhythm in the opposite direction could be expected to produce a decline in PWC. A decrease in PWC% was, however, not seen in the present series of patients with changed heart rhythm (Group II). Thus it can be concluded that commissurotomy in the present study produced a long-lasting, beneficial effect on PWC in all three groups of patients.

III. ECHOCARDIOGRAPHIC LONG-TERM FOLLOW-UP STUDY AFTER CLOSED MITRAL COMMISSUROTOMY

a. Results

1. Preoperative evaluation

The mean preoperative E-F slope in the entire series (n=148) was 17.6±5.5 mm/sec (range, 7 to 39 mm/sec), and the mean D-E amplitude was 17.6±3.7 mm (range, 7 to 26 mm).

2. Early postoperative evaluation

α) Overall results.
The *mean E-F slope*, as measured in 135 patients within the first 100 days after surgery (Fig. 7, p. 26), was 37.2±7.7 mm/sec (range, 18 to 64 mm/sec). The mean preoperative E-F slope (in this group) was 17.5±5.6 mm/sec, with a mean increase after surgery of 19.6±7.5 mm/sec (range, 7 to 43 mm/sec). The *mean D-E amplitude* (measurable in 130 patients) was 18.3±3.5 mm, as compared to 17.5±3.7 mm preoperatively.

β) In relation to preoperative cinefluorographic findings.
The preoperative cinefluorographic study, performed in 132 of the 135 patients examined within 100 days after surgery, showed mitral valvular calcification in 34 patients (26%). The *mean E-F slope* was postoperatively more reduced in patients with valvular calcification, as compared to those without ($p<0.01$) (Table XV). There was no difference in the mean increase of the E-F slope in patients with or without valvular calcification, respectively.

The *mean D-E amplitude* was also more reduced in patients with valvular calcification (Table XVI). The differences were significant both preoperatively ($p<0.001$) and postoperatively ($p<0.001$).

Table XV: Mean (±SD) E-F slope (mm/sec) preoperatively and early postoperatively related to valvular calcification, as evaluated by preoperative cinefluorography.

Echocardiography	Cinefluorography		Difference: valvular calcification vs. no valvular calcification
	Valvular calcification (n=34)	No valvular calcification (n=98)	
Preoperative E-F slope	16.0 ±5.5	18.1 ±5.6	N.S.
Postoperative E-F slope	34.2 ±6.1	38.4 ±7.9	p<0.01
Change in E-F slope pre- vs. postoperatively	+18.2 ±6.0	+20.3 ±8.0	N.S.

Table XVI: Mean (±SD) D-E amplitude (mm) preoperatively and early postoperatively, as related to preoperative cinefluorography.

Echocardiography	Cinefluorography		Difference: valvular calcification vs. no valvular calcification
	Valvular calcification (n=33)	No valvular calcification (n=94)	
Preoperative D-E amplitude	14.8 ±3.7	18.4 ±3.2	p<0.001
Postoperative D-E amplitude	16.2 ±3.6	19.3 ±2.9	p<0.001

γ) E-F slope as related to preoperative D-E amplitude in patients without valvular calcification.

The *mean E-F slope* was similar in patients with D-E amplitude ≤18 mm and in patients with D-E amplitude ≥19 mm before as well as after surgery (Table XVII). There was no difference in the mean increase of the E-F slope after surgery in the two groups with reduced and normal D-E amplitude, respectively.

Table XVII: Mean (±SD) E-F slope (mm/sec) preoperatively and early postoperatively as related to preoperative D-E amplitude in patients without mitral valvular calcification.

E-F slope	D-E amplitude ≤18 mm (n=40)	D-E amplitude ≥19 mm (n=58)	Difference: D-E amplitude ≤18 mm vs. ≥19 mm
Preoperative	17.9 ±5.8	18.3 ±5.5	N.S.
Postoperative	36.8 ±7.6	39.5 ±7.9	N.S.
Change pre- vs. postoperative	+18.9 ±7.6	+21.3 ±8.1	N.S.

3. Late postoperative evaluation

α) Overall results.

The *mean E-F slope* in regularly examined patients (n=53, p. 26) decreased from 38.1±7.9 mm/sec soon after surgery to 28.8±11.4 mm/sec 10-15 years after surgery (Table XVIII). The mean E-F slope in all patients examined at a certain time interval after surgery showed a similar decrease from 37.2±7.7 mm/sec (n=135) to 28.4±10.3 mm/sec (n=108), respectively (Table XVIII).

Table XVIII: Mean (±SD) E-F slope (mm/sec) preoperatively and at different time intervals postoperatively. d. = days. y. = years.

Patient group	E-F slope Pre-operatively	Postoperatively ≤100 d.	≈ 1 y.	≈ 5 y.	10-15 y.
Regularly examined patients (n=53)	18.2 ±5.8	38.1 ±7.9	35.4 ±7.1	33.2 ±8.3	28.8 ±11.4
All patients (no. within brackets	17.6 ±5.5 (n=148)	37.2 ±7.7 (n=135)	34.0 ±7.2 (n=116)	31.9 ±8.1 (n=74)	28.4 ±10.3 (n=108)

Table XIX: Mean (±SD) decrease of E-F slope (mm/sec) during different time intervals after commissurotomy. d. = days. y. = years.

Time interval	Change in E-F slope	No. of observations
100 d. ⟶ 1 y.	-3.3 ±5.0	110
1 y. ⟶ 5 y.	-2.4 ±4.4	66
5 y. ⟶ 10-15 y.	-4.2 ±6.7	65

A gradual, slow decrease of the mean E-F slope with time was observed, and was apparently most pronounced during the first postoperative year (-3.3 mm/sec) (Table XIX).

The distribution of the individual E-F slopes 10-15 years after surgery (n=108) showed that 28 patients had an E-F slope ≤ 20 mm/sec, while an E-F slope >40 mm/sec was found in 9 patients (Fig.15).

The *mean D-E amplitude* 10-15 years after surgery (n=108) was 16.5±4.0 mm.

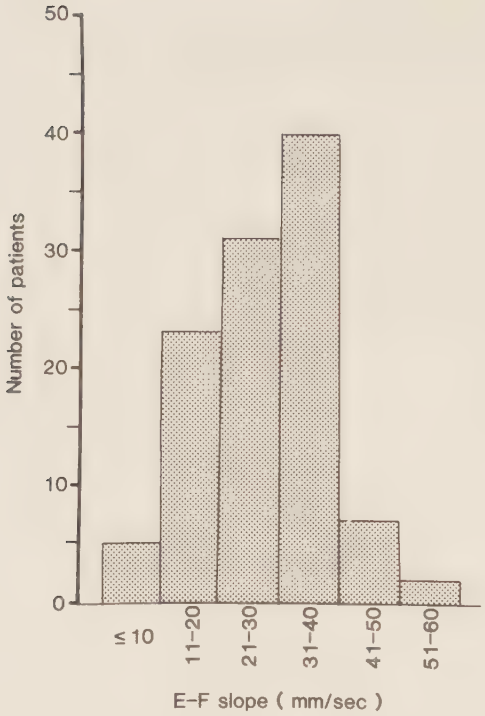


Fig 15: Distribution of individual E-F slopes in single operated patients (n=108) 10-15 years after commissurotomy.

β) E-F slope in in relation to preoperative cinefluorographic findings. Patients with a preoperative finding of calcific mitral valve deposits had a more reduced E-F slope at the 10-15 year follow-up study than did patients with no calcific deposits at the time of surgery ($p<0.001$) (Table XX). This was true also if the results of the last echocardiographic examination after surgery (performed at an average of 10.4±5.4 and 11.6±4.4 years after surgery in patients with and without valvular calcification, respectively) were compared (Table XX).

γ) E-F slope in relation to preoperative D-E amplitude in patients without valvular calcification (at the time of surgery).

The E-F slope (10-15 year after surgery) was the same in patients with a preoperative D-E amplitude ≤18 mm and in those with a D-E amplitude ≥19 mm (Table XXI). When the mean E-F slopes in the two groups of patients were calculated from the last postoperative echocardiographic recording of each patient, a difference ($p<0.01$) was found in E-F slope related to

Table XX: Mean (±SD) E-F slope (mm/sec) at follow-up, as related to preoperative cinefluorography.

Echocardiography	Cinefluorography		Difference: valvular calcification vs. no valvular calcification
	Valvular calcification	No valvular calcification	
E-F slope 10-15 years after surgery (n=106)	21.7±9.1 (n=25)	30.7±9.7 (n=81)	p<0.001
Last recorded E-F slope after surgery (n=138)	22.9±8.9 (n=35)	30.4±9.5 (n=103)	p<0.001

Table XXI: Mean (±SD) E-F slope (mm/sec) at follow-up, as related to preoperative D-E amplitude (in patients without mitral valvular calcification).

E-F slope	D-E amplitude		Difference: D-E ≤18 mm vs. D-E ≥19 mm.
	≤18 mm	≥19 mm	
10-15 years after surgery (n=81)	28.1±8.8 (n=28)	32.0±10.0 (n=53)	N.S.
At last examination after surgery (n=103)	27.5±7.8 (n=41)	32.4±10.1 (n=62)	p<0.01

preoperative D-E amplitude (Table XXI). The time interval between surgery and the last postoperative echocardiogram was from one month to 15.8 years, with an average of 10.5±4.2 and 12.3±4.4 years in patients with a preoperative D-E amplitude ≤18 mm and ≥19 mm, respectively.

4. Evidence of restenosis

Echocardiographic signs of restenosis (E-F≤20 mm/sec) were found in 35 patients (30%) within 10-15 years after commissurotomy (Table XXII), while 80 patients had an E-F slope >20 mm/sec at the 10-15 year follow-up study.

Table XXII: Restenosis (E-F≤20 mm/sec) within 10-15 years after commissurotomy.

	No. of patients	%
Restenosis	35	30
No restenosis	80	70
	115	100
Unknown	28	
Total	143	

The E-F slope at the investigation one year after surgery turned out to be of prognostic value. Thus, among 16 patients with E-F slope ≥40 mm/sec at the one-year postoperative control, none was found to have restenosis at the end of follow-up; furthermore, restenosis had occurred in all 21 patients with E-F slope ≤29 mm/sec one year after surgery (Table XXIII). On the other hand, the E-F slope immediately after surgery was of limited prognostic value regarding a future restenosis. Thus, in six cases restenosis occurred although the early postoperative E-F slope was ≥ 40 mm/sec.

Table XXIII: Restenosis (E-F≤20 mm/sec) within 10-15 years after commissurotomy as related to E-F slope one year after surgery.

E-F slope (mm/sec) one year after surgery	No. of patients	Restenosis	
		n	%
≤29	21	21	100
30-39	62	9	15
≥40	16	0	0
Total	99[a]	30[b]	

a) 116 patients examined - in 17 it remained unknown whether restenosis occurred or not. b) Another 5 patients with restenosis had no one-year postoperative examination.

Restenosis within 10-15 years after commissurotomy was found in 61% of the patients with a preoperative finding of mitral valvular calcification (as evaluated by cinefluorography), but only in 20% of the patients without valvular calcification ($p<0.001$) (Table XXIV). The incidence of restenosis in patients without valvular calcification and with a D-E amplitude ≥19 mm at the preoperative examination was 15%, as compared to 29% in patients with a preoperative D-E amplitude ≤18 mm (N.S.).

The initial echocardiographic results of commissurotomy in patients with restenosis within 10-15 years after surgery are summarized in Table XXV. Six of 35 patients with restenosis during follow-up had an early postoperative E-F slope ≥40 mm/sec. A true restenosis had probably occurred in these cases. In 16 patients the early postoperative E-F slope was ≤29 mm/sec, probably indicating some degree of residual stenosis. The remaining 13 patients with restenosis had an early postoperative E-F slope ranging from 30 to 39 mm/sec, thereby representing an intermediate group. A true restenosis was thus found in only 17% of those having an E-F slope ≤20 mm/sec during the follow-up period.

Table XXIV: Restenosis (E-F≤20 mm/sec) within 10-15 years after commissurotomy related to preoperative mitral valvular calcification (as estimated by cinefluorography) and preoperative D-E amplitude in patients without calcification.

xxx = $p<0.001$. N.S. = non significant.

Preoperative mitral valve characteristics	No. of patients	Restenosis n (%)	
Calcification	28	17 (61)	xxx
No calcification	85	17 (20)	xxx
D-E ≤18 mm	31	9 (29)	N.S.
D-E ≥19 mm	54	8 (15)	N.S.
Total	113	34	

Table XXV: Early postoperative E-F slope (mm/sec) in patients with restenosis within 10-15 years after surgery (n=35).

E-F slope ≤100 days after surgery	No. of patients	Designation
≤29	16	Residual stenosis
30-39	13	Intermediate group
≥40	6	True restenosis
Total	35	

b) Discussion

With respect to the *early postoperative evaluation*, the E-F slope of 37.2 mm/sec reported here is in accordance with other reports on the immediate effect of commissurotomy on the early diastolic descent rate of the anterior mitral leaflet (Table XXVI). A mean E-F slope of 35-50 mm/sec is thus a common finding in patient series evaluated soon after surgery.

The mean increase of the E-F slope in patients with mitral valvular calcification was not different from the increase in those without calcification. A similar satisfactory early effect of surgery in patients with valvular calcification has previously been reported by Edler (26).

In the present investigation, no difference in the early postoperative E-F slope was found between patients with normal and reduced D-E amplitude (in the preoperative evaluation), indicating that the immediate effect of commissurotomy might also be satisfactory in patients without calcification but with a reduced pliability of the mitral leaflets.

The E-F slope increased after surgery in all patients in the present series. Although the E-F slope is determined not only by the degree of mitral stenosis (cf. p. 34), one might expect this increase to correlate with the widening of the mitral valve orifice. Other factors affecting the E-F slope, e.g., left ventricular compliance or aortic valve disease, presumably do not change soon after commissurotomy.

As to the *late postoperative evaluation*, the decrease of the E-F slope was about 9 mm/sec during 10-15 years, which compares favourably with previous studies reporting a mean decrease of the E-F slope from 9 mm/sec during one year to 11 mm/sec during 7.5 years (Table XXVII).

The decrease of the E-F slope was most pronounced during the first postoperative year. Edler made a similar observation in 1967 (26), finding a slight "restenosis" in some patients during the first months after surgery but a constant E-F slope later on in most patients investigated up to three years after commissurotomy.

The long-term decrease of the E-F slope was most marked in patients with valvular calcification (at the time of surgery). A reduced preoperative

Table XXVI: The immediate result of closed commissurotomy on the E-F slope, as presented in some previously published studies.

Calc. = mitral valvular calcification.

Authors	No. of patients	Mean E-F slope (mm/sec)		Comments
		Preoperatively	Postoperatively	
Joyner et al. 1963 (70)	35	16	36	
Heidel et al. 1966 (56)	78	22.0	57.5	
Buhr et al. 1967 (13)	30	12.6	47.9	
Effert 1967 (29)	279	-	-	Mean increase of E-F slope: 24.5 mm/sec
Edler 1967 (26)	84	15.8	44	No calc.
		18	38.4	Slight calc.
	40	14.4	39	Moderate calc.
		11.8	33	Extensive calc.
Wirth et al. 1970 (145)	16	21.7	44.0	Preop. E-F 19-33 mm/sec
	60	14.6	39.0	Preop. E-F 11-18 mm/sec
	19	8.6	38.6	Preop. E-F <10 mm/sec
Bellin & Töwe 1975 (6)	135	21	50	
Pathak et al. 1976 (106)	38	17.3	37.1	No calc.
	12	10.7	24.3	Calc.
Ikäheimo & Takkunen 1977 (64)	14	16	37	
Pezzano et al. 1977 (110)	46	12.5	29.4	
Staśkiewicz et al. 1977 (131)	80	24	41	
Grimberg et al. 1980 (49)	50	16	37	

Table XXVII: Early and late results of commissurotomy on the E-F slope, as presented in some previously published studies.

Authors	No. of patients	Mean postoperative E-F slope (mm/sec)		Mean time (years) between examinations
		Early	Late	
Heidel et al. 1966 (56)	74	57.5	35.7	3
Bellin & Töwe 1975 (6)	135	50	39	7.5
Ikäheimo & Takkunen 1977 (64)	14	37	28	1
Leutenegger et al. 1979 (78)	21	52.6	44.8	4

Comment: In the study by Leutenegger et al., only asymptomatic patients after open commissurotomy were examined.

D-E amplitude in the absence of valvular calcification had no prognostic adverse effect on the E-F slope obtained 10-15 years after surgery. Patients surviving 10 years or more might, however, represent a selected group with less severe disease. This potential selection is avoided by using the last recorded postoperative echocardiogram of each patient for comparison. A more reduced E-F slope in patients with a preoperative D-E amplitude $\leq$18 mm than in those with D-E amplitude $\geq$19 mm was found in such a comparison ($p<0.01$). The mean observation time after surgery was almost two years shorter in patients with a reduced preoperative D-E amplitude than in those with a normal amplitude. As there is a gradual decrease of the E-F slope with time, the difference between the two groups might be even more marked. Also in the absence of valvular calcification, the preoperative finding of a reduced D-E amplitude was thus found to be of prognostic importance, resulting in a significantly more reduced E-F slope at long-term follow-up. On the other hand, the most favourable long-term echocardiographic result after commissurotomy (as judged from the E-F slope) was seen in patients without mitral valvular calcification and with a normal amplitude of excursion of the anterior mitral leaflet at the time of surgery.

Although a progressive narrowing of the mitral valve orifice probably is the main factor responsible for the gradual decrease of the E-F slope with time, a variety of other factors might also contribute to this decrease. Several investigators have reported functional changes with age in the mitral valve echocardiogram, including decreased E-F slope (39,40). This decrease might be explained by sclerosis of the mitral leaflets and/or decreased compliance of the left ventricle (40). Different regression equations have been presented, permitting calculation of the expected normal E-F slope in various age decades. In the present series, a decrease of the E-F slope in the range from 8 to 13 mm/sec might be expected during the follow-up period, using the regression equations suggested by Gardin et al. (39) and Gerstenblith et al. (40), respectively. These equations have, however, been deduced from the comparison of measurements made on normal subjects in different age groups. The effect of the aging process on rheumatic heart valves is not known. Furthermore, long-term serial studies in individuals have not been performed up to now.

An increased incidence, and progress, of aortic regurgitation were seen during the time span of the present investigation. These may also influence the E-F slope at follow-up. It was not possible to evaluate the contribution of these factors on the decrease of the E-F slope, as the degree of aortic regurgitation could not be quantified in the majority of our patients.

As to *restenosis after commissurotomy*, the incidence (within 10-15 years after surgery) was 30% in the present series of patients undergoing commissurotomy irrespective of the condition of the mitral leaflets. A correlation between restenosis and the preoperative presence of mitral valvular calcification was found. In patients without valvular calcification and with a D-E amplitude ≥19 mm (at the time of surgery), the incidence of restenosis was rather low, 15%.

The incidence of restenosis after commissurotomy was unknown for many years. It was believed, however, that the principal cause of recurrent symptoms was unsatisfactory correction of the stenosis at the original operation (52). In order to document recurrent mitral stenosis, a preoperative hemodynamic study with assessment of the severity of the stenosis is needed, followed by a postoperative study in which the relief

of the stenosis is documented and a subsequent study in which the recurrence of important mitral valvular obstruction is demonstrated (60). There are only a few studies in which these criteria were fulfilled. Lyons et al. (84) found restenosis in three of 12 patients three to five years after a documented successful commissurotomy. Higgs et al. (60) performed early and late postoperative catheterization in 45 patients. Although the late hemodynamic studies in all cases were performed because of persistent or recurrent symptoms (at an average of 6.5 years after commissurotomy), restenosis was documented only in five patients (11%). The most common cause of recurrent symptoms was residual mitral stenosis with or without operatively induced mitral regurgitation. In a study by Heger et al. (55), five of 18 patients (28%) had restenosis at late postoperative investigations, performed 10-14 years after a proven successful commissurotomy.

Thus, some data are now available concerning the long-term effect of mitral commissurotomy on mitral valve area. The real incidence of restenosis and residual stenosis in large series of unselected patients is, however, not fully known. A different approach to the problem was used in the present study. Although the exact incidence of restenosis can not be determined using the E-F slope as an index of the severity of mitral stenosis, the present study gives an estimation of the incidence of restenosis (and residual stenosis) in a large series of consecutive patients followed for 10-15 years after commissurotomy.

The present data permit certain conclusions. In patients with restenosis at follow-up, the principal cause was residual stenosis rather than true restenosis, in agreement with previous reports (52,60). Secondly, an echocardiographic examination one year after surgery might be of prognostic value regarding the risk of future restenosis. A poor prognosis regarding restenosis was thus seen in patients with an E-F slope $\leq$29 mm/sec one year after surgery, while, by contrast, restenosis within the first decade after commissurotomy was not seen in patients with a one-year postoperative E-F slope $\geq$40 mm/sec. Echocardiographic signs of true restenosis will thus appear soon after surgery in most cases.

IV. MITRAL VALVULAR CALCIFICATION AFTER CLOSED COMMISSUROTOMY. A LONG-TERM CINEFLUOROGRAPHIC FOLLOW-UP WITH ECHOCARDIOGRAPHIC CORRELATIONS.

a. Results

In the preoperative study mitral valvular calcification was found in 23% of the patients (n=100) with an incidence of 34% and 18% in males and females, respectively. At follow-up, the incidence of calcific deposits in the mitral valve had increased to 52%, and progress in valvular calcification was found in 38% of the patients altogether (Table XXVIII). The calcific deposits were localized to the valve leaflets in all patients, but in 12 of the 34 patients with moderate and heavy calcification a localization to the annulus was found as well. Additional calcification was found in the aortic valve (15 cases), coronary arteries (five cases) and pericard (two cases).

Table XXVIII: Mitral valvular calcification (as evaluated by cinefluorography) 10-15 years after commissurotomy compared to preoperative status (n=100).

Preoperative grading of mitral valv. calc.		Postoperative grading of mitral valvular calcification			
Mitral valv. calcification	No. of patients	0	+	++	+++
0	77	48	18	9	2
+	2	0	0	2	0
++	16	0	0	12[a]	4
+++	5	0	0	0	5
Total	100	48	18	23	11

a) Progress of calcification within the same group was observed in 3 patients.

Table XXIX: Relationship between mitral valvular calcification (as evaluated by cinefluorography) and age and sex 10-15 years after commissurotomy.

Mitral valve calcification	Age (years) 25-40 M	F	41-50 M	F	51-60 M	F	61-80 M	F	Subtotal M	F	Total M + F
0	1	0	3	6	6	15	8	9	18	30	48
+	0	1	0	1	2	6	1	7	3	15	18
++	0	0	0	0	4	6	2	11	6	17	23
+++	0	0	0	0	3	1	2	5	5	6	11
Total	1	1	3	7	15	28	13	32	32	68	100

The relationship between age, sex and mitral valvular calcification at follow-up is apparent i Table XXIX. A higher incidence of valvular calcification in females than in males was observed (56% vs. 44%), in contrast to the preoperative findings. In the group with heavy calcification, however, there was a higher male prevalence than expected, but the number of patients was rather small (n=11).

Among 77 patients without detectable mitral valvular calcification at the time of surgery, 29 (38%) developed calcific deposits within 10-15 years. The preoperative echocardiographic examination did not reveal any differences regarding D-E amplitude or E-F slope between those who later developed calcification and those who did not (Table XXX).

Table XXX: Mean (±SD) preoperative D-E amplitude (mm) and E-F slope (mm/sec) in patients without mitral valvular calcification at commissurotomy (n=77), as related to cinefluorographic findings 10-15 years after surgery.

Preoperative echocardiography	Postoperative cinefluorography		Difference: valvular calcification vs. no valvular calcification
	Valvular calcification (n=29)	No valvular calcification (n=48)	
D-E amplitude	18.6 ±2.8	19.3 ±3.1	N.S.
E-F slope	19.3 ±6.3	17.8 ±5.5	N.S.

After dividing the patients into different groups according to their cinefluorographic appearances, the results of the echocardiographic measurements at follow-up were evaluated (Table XXXI). D-E amplitude as well as E-F slope were more reduced in patients with moderate (++) calcification, as compared to those with light (+) calcification ($p<0.05$). In general, there was a decline in both D-E amplitude and E-F slope with

increasing calcific deposits, but a considerable overlapping between the different groups was found.

Table XXXI: Mean (±SD) D-E amplitude (mm) and E-F slope (mm/sec) as related to mitral valvular calcification (as evaluated by cinefluorography) 10-15 years after commissurotomy. The range is shown within brackets.
x = p<0.05. xxx = p<0.001. N.S. = non significant.

Analysis of variance (ANOVA): 1) D-E amplitude: F = 10.2, p<0.001.
2) E-F slope: F = 6.8, p<0.001.

Echocardiography	Cinefluorography grading of mitral valvular calcification			
	0 (n=48)	+ (n=18)	++ (n=23)	+++ (n=11)
	xxx			
	xxx			
D-E amplitude	18.5±3.2 (9-26)	17.1±2.6 (12-22)	14.8±4.3 (9-22)	13.1±4.4 (8-21)
	N.S.	x	N.S.	
E-F slope	31.9±9.5 (15-52)	30.5±10.4 (8-56)	22.7±9.2 (5-37)	21.7±10.0 (9-39)
	xxx			
	xxx			

In the comparison between cinefluorographic and echocardiographic identification of mitral valvular calcification, it was found that patients demonstrating heavy calcification by one technique were also found to be abnormal by the other (Table XXXII). However, in the group with light calcification according to one technique, the result obtained using the other technique was unpredictable.

Table XXXII: Relation between cinefluorographic and echocardiographic identification of mitral valvular calcification.

Grading of calcification: a) Cinefluorography: 0 = none. + = light. ++ = moderate. +++ = heavy. b) Echocardiography: 0 = none. + = light ++ = heavy.

Cinefluoro-graphy	Echocardiography			Total
	0	+	++	
0	7	41	0	48
+	3	12	3	18
++	0	10	13	23
+++	0	2	9	11
Total	10	65	25	100

b. Discussion

Ten to 15 years after mitral commissurotomy, cinefluorographic evidence of calcific deposits in the mitral valves was found in 52% of the patients, and progress in valvular calcification (as compared to the preoperative examination) was observed in 38%.

Cinefluorography has been shown to be a very specific, although not very sensitive, technique for determining the presence of calcification (98). The true incidence of mitral valvular calcification is, therefore, probably higher than observed, particularly at the time of the pre-operative cinefluorography. During the time span of the investigation (more than 10 years), a considerable technical improvement, especially of image intensifiers, has occurred, increasing the sensitivity of the technique. Small calcific deposits found at follow-up might, therefore, have passed undetected at the preoperative examinations. The percentage of patients showing progress in their valvular calcification might then also be overestimated.

The present series consists of highly selected patients with mitral stenosis, all having a closed commissurotomy performed 10-15 years ago.

It has been reported that the amount of calcific deposits in stenotic mitral valves does not appear to correlate with previous commissurotomy (76). Thus, surgery per se does not accelerate valvular calcification.

Preoperatively, a higher incidence of valvular calcification in males than in females was recorded (34% vs. 18%), in accordance with several previously published studies (74,76,92,102). The progress of calcification was, however, most marked in females, leading to a reversed situation 10-15 years after surgery (with the highest incidence of calcification in females), although the males still were relatively over-represented in the group with heavy calcification. It is well known that males tend to have calcific deposits in stenotic mitral valves at an earlier age than do females (76). The results of the present follow-up study (in which the mean age of the patients was 59.3 years) might indicate that the difference between males and females regarding calcification will disappear at higher ages.

The amplitude of movement of the anterior mitral valve measured on the echocardiogram represents the displacement of the valve cusp from the closed to the open position. A reduced mobility may be due to the fusion of commissures, thickening of the cusps, fusion or shortening of the subvalvular apparatus or a combination of these factors (142). A reduced valve mobility might be expected to be more common in patients with an advanced mitral stenosis as compared to patients with a pure commissural type of stenosis, leading to a more disrupted flow pattern through the mitral orifice. According to the theory proposed by Selzer et al. (123), this would enhance further stiffening and calcification of the cusps. In the present study, however, the measurement of the amplitude of movement of the anterior mitral leaflet (D-E amplitude) was of no value in predicting later development of calcific deposits in the mitral valve.

At follow-up, light calcification (+) had no influence on D-E amplitude or E-F slope, but higher degrees of calcification (++/+++) were associated with a reduction of both these echocardiographic variables ($p<0.001$).

Echocardiographic evidence of heavy valvular calcification or absence of calcification was found to correlate with the cinefluorographic findings. On the other hand, in the group with light calcification there was no close relationship between the results obtained by the two

techniques. The reason for this is probably that echocardiography is unreliable in the differentiation between fibrosis and calcification.

V. POSTERIOR MITRAL LEAFLET MOTION. AN ECHOCARDIOGRAPHIC ANALYSIS 10-15 YEARS AFTER CLOSED COMMISSUROTOMY.

a. Results

An anterior motion of the posterior mitral leaflet during diastole (type 1) was found in 53 patients (50%), while a predominant posterior motion (type 2) was recorded in 10 (9%). The remaining 44 patients (41%) showed an initial posterior motion of the posterior leaflet in diastole, followed by an abnormal anterior motion (type 3). A motion pattern of type 1 could also be obtained in 11 of these patients (25%) by moving or angulating the transducer (Fig.9, panels a + c, page 30).

When the motion patterns of the posterior mitral leaflet were correlated to the results of cinefluorography (n=101), it was found that all patients with heavy mitral valvular calcification (+++) exhibited type 1 motion pattern of the posterior leaflet (Table XXXIII). Only 26% of the patients with this motion pattern had no calcific deposits in the mitral valves as compared to 61% with type 3 motion pattern. There was only one

Table XXXIII: Relationship between mitral valvular calcification (as evaluated by cinefluorography) and different motion patterns of the posterior mitral leaflet 10-15 years after commissurotomy (n=101).

Cinefluoro-graphy	Echocardiography: Motion pattern of posterior mitral leaflet.			Total
	1	2	3	
0	13	9	25	47
+	10	0	9	19
++	16	1	7	24
+++	11	0	0	11
Total	50	10	41	101

patient in the group of 10 with type 2 motion pattern who had valvular calcification, and in this patient most of the calcific deposits were supposed to be located in the mitral valve ring.

The mean E-F slope was more reduced in patients with type 1 motion pattern of the posterior leaflet than in those with motion pattern of type 2 or 3 ($p<0.001$) (Table XXXIV). Also regarding the D-E amplitude a difference was found between patients with type 1 and type 3 motion patterns, with a lower value in the first group ($p<0.05$). No differences in E-F slope or D-E amplitude were found between patients with type 2 and type 3 motion patterns of the posterior mitral leaflet.

Table XXXIV: Mean (±SD) D-E amplitude (mm) and E-F slope (mm/sec) as related to different motion patterns of the posterior mitral leaflet 10-15 years after commissurotomy. The range is shown within brackets. n=107.

x = $p<0.05$. xxx = $p<0.001$. N.S. = non significant.

ANOVA: 1) D-E amplitude: $F = 3.3$, $p<0.05$. 2) E-F slope: $F = 16.4$, $p<0.001$.

Echocardiographic measurements	Motion pattern of posterior leaflet		
	1 (n=53)	2 (n=10)	3 (n=44)
D-E amplitude	15.6±4.2 (8-24)	17.2±3.5 (12-23)	17.6±3.6 (9-26)
	N.S.		x
		N.S.	
E-F slope	23.4±8.6 (5-40)	35.6±9.3 (23-52)	32.9±9.7 (8-50)
	xxx		xxx

b. Discussion

In most cases of mitral stenosis, the posterior mitral leaflet, as seen on the echocardiogram, opens anteriorly, parallel to the anterior leaflet. It has been suggested that such movement is the result of commissural fusion, which pulls the posterior leaflet in a direction similar to that of the anterior leaflet (57). A posterior movement of the posterior mitral leaflet might be explained either by incomplete commissural fusion (35,86) or by cuspal, rather than commissural, disease (79,126, 136). A posterior movement has also been shown to be associated with a thin and mobile posterior leaflet, while an anterior movement more frequently has been found to be associated with extensive disease of the posterior leaflet (135).

Even in mitral stenosis the anterior and posterior leaflets might be moving apart as the whole mitral valve structure moves towards the transducer. Depending on the rate of anterior leaflet motion relative to the rate of separation, one may see an early diastolic posterior motion of the posterior leaflet followed by abnormal anterior motion, which still represents a variant of the rheumatic pattern (111). This motion pattern might be dependent on transducer localization and angulation. The appearance of both normal and abnormal early posterior leaflet motion in the same patient was noted in 11 patients in the present series. This has also previously been documented (42,97).

In the present study 9% of the patients had a normal posterior leaflet motion (type 2) 10-15 years after surgery, as compared to 60% in a series reported by Shiu et al. (126). In the latter report the echocardiograms were obtained shortly after surgery, and this might explain the great difference between the two series. An initial movement of the posterior leaflet in a direction opposite to that of the anterior leaflet was found in 50% of the patients in the present study, as compared to only 22% in another series reported by Thomas et al. (135), in which the echocardiograms also were obtained within one month after mitral valve repair. This great discrepancy might reflect different recording techniques and/or different clinical materials.

Type 1 pattern of posterior leaflet motion was associated with the highest incidence of valvular calcification in the present study. A correlation between the amount of calcific deposits in the stenotic mitral valve and the mean diastolic pressure gradient across the mitral valve has previously been shown (76). The mean E-F slope in patients with type 1 motion pattern was also more reduced than in patients with motion pattern of type 2 or type 3 ($p<0.001$), indicating a more severe stenosis. There are thus two different indices of the presence of a more advanced stenosis in the group of patients with an anterior movement of the posterior mitral leaflet during diastole. Although the motion pattern of the posterior mitral leaflet does not permit any firm judgement about the severity of mitral stenosis in the individual case (42), the present study indicates that an anterior movement of the leaflet is more frequently found in advanced cases of mitral stenosis.

VI. ECHOCARDIOGRAPHICALLY DETERMINED LEFT ATRIAL SIZE IN LONG-TERM SURVIVORS AFTER MITRAL COMMISSUROTOMY AND ITS RELATION TO AGE AND HEART RHYTHM.

a. Results

The individual left atrial dimensions (corrected for body surface area, BSA) ranged from 20 to 51 mm/m^2 BSA (Fig.16). Only four patients (3.7%) in the total series (n=109) had a left atrium of normal size, using 22 mm/m^2 BSA as the upper normal limit for left atrial dimension (33). When the individual values were correlated to heart rhythm, it was found that 78% of the patients with established atrial fibrillation (n=68) had a left atrial dimension exceeding 30 mm/m^2 BSA, as compared to only 21% of the patients in regular sinus rhythm (n=28) (Fig.16).

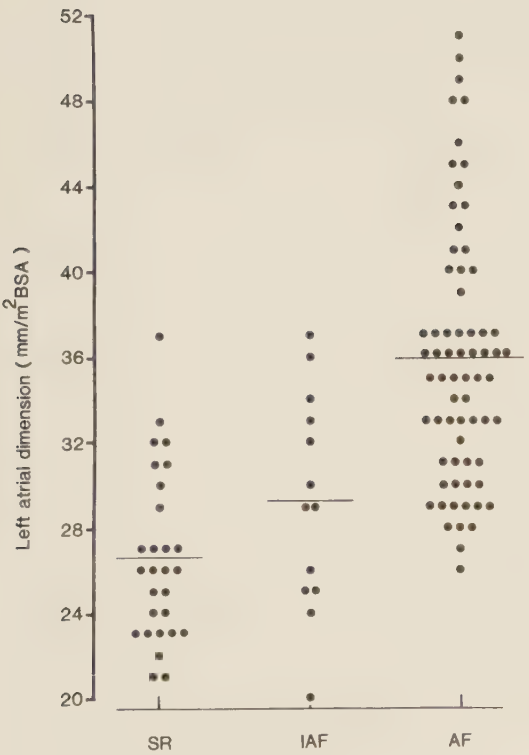


Fig 16: Left atrial dimension (individual patients and mean), as evaluated by echocardiography, related to heart rhythm 10-15 years after commissurotomy (n=109).

SR = sinus rhythm; IAF = intermittent atrial fibrillation; AF = atrial fibrillation.

The mean left atrial dimension was greater in patients with atrial fibrillation than in patients with intermittent atrial fibrillation ($p<0.001$) or in sinus rhythm ($p<0.001$), while no difference was found between patients with intermittent atrial fibrillation and those in sinus rhythm (Table XXXV). The age distribution in the different groups of patients showed a similar pattern (Table XXXV).

Table XXXV: Mean ($\pm$SD) left atrial dimension (mm/m^2 BSA) (as evaluated by echocardiography) and patient age (years) as related to heart rhythm 10-15 years after commissurotomy (n=109).

xxx = $p<0.001$. N.S. = non significant.

ANOVA (left atrial dimension): $F = 31.1$, $p<0.001$.

Echocardiography	Heart rhythm		
	Sinus rhythm (n=28)	Intermittent atrial fibrillation (n=13)	Atrial fibrillation (n=68)
	xxx		
Left atrial dimension	26.6 $\pm$4.0	29.2 $\pm$5.1	35.9 $\pm$6.1
	N.S.		xxx
Age	54.9 $\pm$8.2	55.3 $\pm$9.1	63.3 $\pm$7.1

In the group with established atrial fibrillation (n=68), the duration of the arrhythmia could be assessed in 66 patients. The relationship between the duration of atrial fibrillation and left atrial dimension is shown in Table XXXVI. A small but progressive increase of left atrial size and mean age of the patients was found with increasing duration of atrial fibrillation. The mean left atrial dimension was thus 40.0 mm/m^2 BSA in patients with atrial fibrillation for more than 20 years, as compared to 32.4 mm/m^2 BSA in those with a duration of the arrhythmia of less than six years ($p<0.01$).

Table XXXVI: Mean (±SD) left atrial dimension (mm/m^2 BSA) (as evaluated by echocardiography) and patient age (years) as related to duration of atrial fibrillation (years) (n=66).

x = $p<0.05$. xx = $p<0.01$. N.S. = non significant.

ANOVA (left atrial dimension): $F = 4.0$, $p<0.01$.

Echocardiography	Duration of atrial fibrillation				
	≤5 (n=15)	6-10 (n=13)	11-15 (n=16)	16-20 (n=11)	>20 (n=11)
Left atrial dimension	32.4 ±4.7	33.5 ±4.7	36.5 ±5.9	38.3 ±6.5	40.0 ±6.6
Age	61.0 ±7.5	62.2 ±8.1	62.5 ±6.1	64.4 ±6.2	65.2 ±5.4

N.S. (32.4 vs 33.5); x (32.4 vs 36.5); xx (32.4 vs 38.3); xx (32.4 vs 40.0)

b) Discussion

The presence of atrial fibrillation was found to be closely related to the degree of left atrial dimension and to the age of patients in the present study. A similar, significant relationship between atrial fibrillation and left atrial dimension has previously been found, using measurements that are either corrected (65,125) or uncorrected (32,58,125) for body surface area.

A significant relationship between left atrial dimension and duration of the arrhythmia in patients with atrial fibrillation was also found. This seems to be in contrast to the findings in a study by Probst et al. (112), who concluded that the duration of the arrhythmia had little definitive relationship to left atrial size. In their study, however, a grossly enlarged left atrium was found in only 12% of the patients with chronic atrial fibrillation of five years' duration or less, as compared to in

44% of the patients with a duration of the arrhythmia exceeding five years.

In the present study the mean left atrial dimension was smallest in the group of patients with regular sinus rhythm, showing a small increase in patients with intermittent atrial fibrillation and a further progressive increase in patients with chronic atrial fibrillation, significantly related to the duration of the arrhythmia. It has been argued that, if left atrial dilatation is the cause of atrial fibrillation, left atrial size should be smallest in patients with sinus rhythm, largest in patients with chronic atrial fibrillation, and intermediate in patients with intermittent atrial fibrillation (112). Such a relationship was not found by Probst et al. (112) while, in another report, Henry et al. (58) were able to demonstrate a close relationship between left atrial size and heart rhythm.

A pathophysiological mechanism for atrial fibrillation in mitral valve disease has previously been proposed by Henry et al. (58). According to their hypothesis, a chronic hemodynamic burden initially produces atrial dilatation and, possibly, structural damage to the atrial wall. Atrial dilatation in turn increases the likelihood of the development of atrial fibrillation. A close relationship between age (duration of mitral valve disease), as well as left atrial dimension, and the occurrence of atrial fibrillation is in accordance with this theory. Once atrial fibrillation is present, atrial dilatation could progress as a consequence of either the continued hemodynamic burden, the loss of atrial systole, or both. A progressive increase of left atrial size with increasing duration of the arrhythmia could thus be anticipated, and this was also confirmed by the present study.

SUMMARY OF OVERALL LONG-TERM SURGICAL RESULTS IN PATIENTS SUITABLE FOR CLOSED COMMISSUROTOMY

I. INTRODUCTION

In the present series of 148 surgically treated patients with mitral stenosis, closed commissurotomy was performed irrespective of the condition of the mitral leaflets. Open heart surgery would certainly have been preferred today in many of these cases, especially in those with mitral valvular calcification and more than trivial mitral regurgitation. The results of the present follow-up study are, therefore, probably not representative for patients undergoing closed commissurotomy currently. In the following presentation the long-term results of surgery have been evaluated in a sub-series of younger patients regarded as suitable for closed mitral commissurotomy.

II. MATERIAL

Patients regarded as suitable for commissurotomy had to fulfill all of the following preoperative criteria: 1) no valvular calcification (as evaluated by cinefluorography); 2) D-E amplitude ≥19 mm; 3) age <50 years; and 4) no mitral regurgitation, or a regurgitant jet palpable not more than one finger from the mitral orifice (at surgery). There were 43 patients (nine men and 34 women) with these characteristics. Their mean age at the time of surgery was 40.0±6.7 years (range, 21 to 49 years), and 21% had atrial fibrillation.

III. RESULTS

a. Early and late mortality

No patient died in the peroperative period. The ten-year survival percentage was 93% (40/43). The causes of death were heart failure (one case), sudden death (one case), and cerebral embolism (one case). The patient who died from an embolic event had a severe mitral regurgitation caused by surgery 6 months earlier.

b. Reoperations

Two patients (4.7%) were reoperated during the first decade after surgery. One patient had a closure of a cleft in the anterior mitral leaflet, caused by surgery, and the other had a second closed commissurotomy.

c. Clinical disability

A functional classification (NYHA) was possible in 31 single operated patients 10-15 years after surgery. Twelve patients belonged to function class I, ten patients to class II, and nine patients to class III A. Fifty-one percent (22/43) of all patients in this series were thus in function class I or II 10-15 years after commissurotomy, without any secondary procedure to the mitral valve.

d. Mitral valvular calcification

Cinefluorography was performed in 38 patients 10-15 years after surgery. Calcific deposits in the mitral valves were found in nine patients (24%). The calcifications were graded light (+) in seven cases and moderate (++) in two cases.

e. Physical working capacity

A conclusive exercise test was performed preoperatively as well as 10-15 years postoperatively in 31 patients (72%). Twenty-six of these patients had unchanged heart rhythm throughout the observation period (19 sinus rhythm and seven atrial fibrillation). The heart rhythm had changed from sinus rhythm preoperatively to atrial fibrillation at follow-up in five patients.

The physical working capacity, expressed as percentage of the normal value related to age (PWC%), was 42.4±12.8 preoperatively. At follow-up it had increased to 56.6±19.2 ($p<0.001$).

f. Echocardiographic evaluation

An echocardiographic examination was performed in 37 single operated patients 10-15 years after surgery. The mean E-F slope was 33.0±10.5 mm/sec, as compared to 18.2±5.2 mm/sec preoperatively.

Restenosis (E-F≤20 mm/sec) within 10-15 years after surgery was found in six of 38 patients (16%). Three of these patients were borderline cases with an E-F slope of 20 mm/sec. A true restenosis was found in two patients and a residual stenosis in one. The remaining three patients belonged to the intermediate group (cf. p. 69).

IV. DISCUSSION

In the present, younger group of patients with pliant, non-calcified mitral valves, the long-term results of closed commissurotomy were rather satisfactory. An excellent long-term survival percentage was recorded, and the functional results were also satisfactory with more than half of the patients (51%) being in functional class I-II 10-15 years after surgery. The physical working capacity (PWC%) was also better at the follow-up study compared to preoperative findings ($p<0.001$).

Echocardiographic evidence of restenosis was found in six patients (16%). Residual stenosis was an uncommon cause of restenosis in this sub-sample of patients, in contrast to the findings in the entire series of 148 patients, reflecting the influence of valve condition on the results of surgery.

Although surgery was performed on patients suitable for closed commissurotomy, a severe mitral regurgitation was caused by surgery in two patients (4.7%). Therefore, it is advisable to have on stand-by a pump oxygenator, making an immediate open-heart procedure possible, when closed mitral commissurotomy is performed, as previously stressed by, e.g., Turina et al. (137).

Closed mitral commissurotomy was thus found to be an acceptable surgical procedure in a selected group of patients with mitral stenosis. Long-lasting palliation was seen in the majority of patients under the age

of 50 with pliant, non-calcified, and competent mitral valves at the time of surgery. The progressive nature of rheumatic mitral valve disease was, however, demonstrated by, e.g., the occurrence of mitral valvular calcification in 24% of the patients 10-15 years after surgery.

GENERAL DISCUSSION

The results of *surgical treatment* of mitral stenosis have been extensively described in the literature. The selection of patients, technique of surgery, and the surgeon's experience are all factors that may influence the results, making a comparison between different series of patients difficult. Several studies have confirmed that the natural history of mitral stenosis has been altered by mitral commissurotomy (48, 89, 100). Patients operated on for mitral stenosis have a prolonged life and improved functional capacity compared to medically treated patients. Their long-term survival is, however, less than that of the general population, showing that commissurotomy is a palliative procedure, not a cure (31,100).

As to the operative technique, an *instrumental commissurotomy* was performed in all patients in the present series. After the introduction of a transventricular dilator, a striking increase in the incidence of complete anterior and posterior commissural division was found (82). The transventricular instrumental commissurotomy is thus generally believed to be superior to digital commissurotomy, although there is little hemodynamic confirmation of this assumption (34). When comparing instrumental and digital commissurotomy by hemodynamic studies, Gobel et al. (44) found no difference in the enlargement of the mitral valve area between the two groups, although those patients who had the largest postoperative mitral valve area had undergone an instrumental commissurotomy.

The advantages and disadvantages of *open mitral commissurotomy* have been discussed in details by others (10,37,91,119). Excellent long-term results achieved by the open procedure have recently been reported (50,91). As shown in the present study, satisfactory long-term results will also follow after closed commissurotomy in many patients. It is, however, difficult to compare long-term results of the open and closed methods of mitral commissurotomy because of the differences in patient selection and because of the different eras of cardiac surgery that the literature represents (119). The important thing is not to sacrifice a reasonable valve in favour of an unnecessary valve replacement (120). An early mitral valve replacement thus carries the disadvantages of uncertain long-term durability, residual gradients, a variable incidence of hemo-

lysis and thromboembolism, and risks for subacute bacterial endocarditis and perivalvular leaks (91).

Of *preoperative factors* associated with unsatisfactory results after commissurotomy, the presence of atrial fibrillation was the most important in the present study. It has also previously been emphasized by, e.g., Werkö (141) that in any given set of patients with mitral stenosis, the incidence of atrial fibrillation is more related to the general severity or duration of the disease than any other physiological characteristic. The adverse effects of mitral valvular calcification (31,71,74) and mitral regurgitation (47) on long-term results of surgery were furthermore confirmed by the present study, although the preoperative incidence of severe mitral regurgitation and heavy valvular calcification was limited to 8.8% and 4.9%, respectively.

Long-term observations after closed commissurotomy are obscured not only by different patient selection but also by the number of patients having a second heart operation during the follow-up period. A *reoperation rate* of only 4.9% during the first 10 years after surgery was found in the present investigation. The results of the study, therefore, more or less reflect the natural course of patients after closed mitral commissurotomy.

A high incidence of *multivalvular disease* among long-term survivors after commissurotomy is indicated by the presence of aortic valvular disease in 44% and tricuspid regurgitation in 16% of the patients at the present follow-up investigation. Physical signs of both mitral and aortic regurgitation were also found in many patients. This potential presence of multivalvular disease renders the physical diagnosis difficult in several ways. The grading of murmurs in patients with a combined lesion might, for example, not be a useful guide to the severity of valvular incompetence (134). It has also been reported that tricuspid regurgitation may masquerade as mitral regurgitation in patients with severe mitral stenosis (1,139). Although it has been shown that in the vast majority of cases the early diastolic murmur audible at the left sternal border is due to aortic regurgitation, and that the Graham Steell murmur of pulmonary regurgitation is a rare entity (117), the existence of Graham Steell murmur has been proved in a small proportion of patients

with moderate to severe pulmonary hypertension secondary to acquired rheumatic valvular disease (88). Although unknown, the incidence of pulmonary regurgitation in the present series is probably very low.

A significant protective value of mitral commissurotomy against *late systemic embolism* has been reported by several investigators (19,48,101), although this has not always been confirmed (72,132). For example, in medically treated patients, Olesen et al. (101) found an incidence of emboli of 3.7% per patient-year, and Greenwood et al. (48) found an incidence of 3.3% per patient-year. The incidence of late emboli after surgery, as recorded by these authors, was 1.0% and 0.5% per patient-year, respectively. The incidence of this complication in the present study (1.1% per patient-year) would probably have been further decreased if all patients with either intermittent or continuous atrial fibrillation had been fully treated with anticoagulants.

A long-term follow-up of *the physical working capacity* (PWC) after commissurotomy was included in the present study. In a longitudinal study over more than one decade the steady decline of working capacity with increasing age must clearly be taken into consideration. In an attempt to eliminate this influence of age, the concept of PWC% was introduced. Although an increase in mean PWC% ($p<0.001$) was still present 10-15 years after surgery (as compared to preoperatively), the PWC% remained considerably reduced (54.9%) at follow-up. This is consistent with other reports on PWC after commissurotomy, in which a return to normal was found in less than 20% of patients examined 0.5-2.9 years after surgery (16,46).

Echocardiography is of undisputable value in diagnosing mitral stenosis (18,111). As shown in the present study, it is also useful in the selection of patients suitable for commissurotomy. A relationship between a reduced preoperative D-E amplitude and a reduced E-F slope at follow-up was thus observed. By an early postoperative echocardiographic examination, various degrees of residual stenosis can also be assessed. The echocardiogram one year after surgery was furthermore found to be of prognostic value regarding future restenosis and might thus be useful in the planning of subsequent follow-up controls.

The echocardiographically determined *left atrial dimension* was found to correlate not only with the presence of atrial fibrillation but also with the duration of the arrhythmia in the present series. As left atrial size appears to be one of the major determinants of the response of atrial fibrillation to therapy (115), this measurement is of great potential clinical value. The evaluation of left atrial diameter by echocardiography might thus help the physician to identify patients in whom cardioversion has little or no chance of long-term success in maintaining sinus rhythm (32,58).

As to *mitral valvular calcification*, it has previously been noted that, in patients with mitral stenosis, operated on more than once, progress of fibrosis and frequently also of calcification of the valve is often seen between operations (138). This clinical observation was further confirmed by the present study, in which progress of valvular calcification was found in 38% of the patients during a time span of 10-15 years. This result apparently supports the conclusion made by Lowther and Turner in 1962: "Although most patients with severe mitral stenosis are improved by valvulotomy, surgical treatment is but an incident in the relentless progress of rheumatic heart disease, whether from activity of the rheumatic process or from the progressive fibrosis which follows activity" (83). On the other hand, the results of the present study confirm that long-lasting beneficial effects are produced by surgery in many patients. In capable hands closed mitral commissurotomy thus appears to be an effective and simple method of palliative treatment for mitral stenosis (119). For the appropriate patient and for the appropriate valve it still has a specific place and should not be totally forgotten in these days of rapidly advancing technology (120).

GENERAL SUMMARY AND CONCLUSIONS

1) 148 consecutive patients with mitral stenosis were followed for 10-15 years after their first closed instrumental commissurotomy, by clinical evaluation, exercise tests, echocardiography, and cine-fluorographic examinations.

2) The perioperative mortality was 3.4% and the 10-year survival percentage was 83%, in agreement with earlier published series, operated in the 1960´s (38,47,137).

3) 27% of those surviving the initial surgery were in functional class I-II (NYHA) 10-15 years after the commissurotomy without any secondary procedure to the mitral valve. Mitral valve calcification, atrial fibrillation, mitral regurgitation, and coexisting aortic valvular disease were adverse factors affecting the long-term prognosis after surgery. Physical signs of concomitant aortic valvular disease were found in 44% of the patients 10-15 years after surgery compared to 31% preoperatively.

4) An exercise test (performed in a sub-sample) confirmed a satisfactory physical working capacity (normal or near-normal) in 27 single operated cases 10-15 years after commissurotomy (19% of those surviving the initial surgery).

5) The incidence of systemic embolism was 1.1% per patient-year, indicating that even after mitral commissurotomy systemic embolism represents a major threat. An adequate long-term anticoagulant therapy in cases with continuous or intermittent atrial fibrillation would presumably reduce the number of embolic events.

6) By echocardiography evaluation, the E-F slope was taken as a marker for the immediate successful outcome of the commissurotomy. A satisfactory result of surgery was found also in patients with a preoperative finding of valvular calcification or a reduced amplitude of excursion of the anterior mitral leaflet (D-E amplitude). However, both mitral valvular calcification and a reduced D-E amplitude had

a significant adverse affect on the E-F slope in the long-term follow-up study.

7) Mitral restenosis (E-F $\leq$20 mm/sec) within the first 10-15 years after surgery was 30%. The principal cause was residual stenosis rather than true restenosis. The E-F slope one year postoperatively could be used as a prognostic indicator for future restenosis. A poor prognosis was seen in patients with E-F slope <30 mm/sec, while in patients with E-F slope $\geq$40 mm/sec restenosis within the first decade after surgery was not seen.

8) The posterior mitral leaflet motion was normal in 9% and an initial posterior motion followed by abnormal anterior motion was found in 41% at the late follow-up study. The classical mitral stenosis finding of an anterior motion of the posterior mitral leaflet in diastole was associated with a more severe stenosis.

9) At the follow-up study, an association between atrial fibrillation and left atrial dilatation was found, by the echocardiographic assessment of left atrial dimension. With increasing duration of arrhythmia there was a progressive increase of left atrial size.

10) By cinefluorograhpy evaluation, a progress of mitral valvular calcification was found in 38%, in agreement with earlier statements of the progressive nature of rheumatic valve disease (83).

11) Closed commissurotomy seems to be a fully acceptable surgical procedure in the operative management of rheumatic mitral valve disease when applied to a selected group of patients with mitral stenosis. The best long-term results should be anticipated in patients without mitral valvular calcification, without mitral regurgitation and with sinus rhythm, and with a normal echocardiographic amplitude of excursion of the anterior mitral leaflet.

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A P P E N D I X

Part I. Normal values for physical working capacity (according to Nordesjö).

Table A. Ages, no. in each agegroup, means and SD (smaller sample size for SD) for physical working capacity (Wmax 6 min), and weight (sample size) for the collected data.

Age (years)		W max 6 min (W)			Weight (kg)	
	n	$\bar{x}$	SD	nSD	$\bar{x}$	n weight
Men						
20.0	3.008	242	37	2429	66.7	1.819
30.9	580	227	33.5	91	76.3	13
42.7	243	204	30	182	77.7	67
55.0	857	169	26.5	820	76.1	104
64.2	75	147	23	39	73.5	28
75.0	22	120	18	22	73.5	11
Women						
22.5	376	164	32	376	58.8	94
33.1	42	150	28	42	57.5	12
43.6	56	134	24	39	65.1	39
55.6	47	120	20	47	63.6	28
65.0	10	112				

Part II. Normal values for physical working capacity related to individual height, weight and body constitution (according to Nordesjö).

The patient is first placed in the proper normal value class (Tables B:I and B:II). The ranges for ordinary and slightly reduced PWC in each class are shown in Table C.

Table B:I. Normal value classes for males.

Adipose tissue	Body constitution (skeleton and muscles)								
	Slender			Ordinary			Sturdy		
	Height (cm)			Height (cm)			Height (cm)		
	≤160	161-189	≥190	≤160	161-189	≥190	≤160	161-189	≥190
Lean	40[a]	50	60	50	60	70	60	70	80
	1[b]	2	3	2	3	4	3	4	5
Ordinary	50	60	70	60	70	80	70	80	90
	1	2	3	2	3	4	3	4	5
Obese	60	70	80	70	80	90	80	90	100
	2	3	4	3	4	5	4	5	6

a) Weight (kg) b) Normal value class.

Table B:II. Normal value classes for females.

Adipose tissue	Body constitution (skeleton and muscles)								
	Slender			Ordinary			Sturdy		
	Height (cm)			Height (cm)			Height (cm)		
	≤150	151-174	≥175	≤150	151-174	≥175	≤150	151-174	≥175
Lean	37[a]	44	51	44	51	58	51	58	65
	1[b]	2	3	2	3	4	3	4	5
Ordinary	44	51	58	51	58	65	58	65	72
	1	2	3	2	3	4	3	4	5
Obese	51	58	65	58	65	72	65	72	79
	2	3	4	3	4	5	4	5	6

a) Weight (kg) b) Normal value class.

Table C. Physical working capacity (W) in different normal value classes.

Physical working capacity	Age	Sex	Normal value class 1	2	3	4	5	6
Ordinary	20-29	M	109-164	132-198	154-230	175-263	198-296	219-329
		F	78-116	90-136	102-154	114-172	127-191	139-209
	30-39	M	103-155	123-185	144-216	165-247	185-277	206-308
		F	73-109	85-127	96-144	107-161	119-179	130-196
	40-49	M	89-133	107-161	125-187	142-214	161-241	178-268
		F	68-102	78-118	90-134	101-151	111-167	122-184
	50-59	M	75-113	90-136	106-158	121-181	136-204	151-227
		F	61- 91	70-106	80-120	90-134	99-144	109-163
	60-69	M	66-100	79-119	93-139	106-160	119-179	133-199
		F	53- 79	62- 94	70-106	78-118	88-132	96-144
Slightly reduced	20-29	M	96-109	116-132	135-154	153-175	173-198	192-219
		F	68- 78	79- 90	90-102	100-114	111-127	122-139
	30-39	M	90-103	108-123	126-144	144-165	162-185	180-206
		F	64- 73	74- 85	84- 96	94-107	104-119	114-130
	40-49	M	78- 89	94-107	109-125	125-142	141-161	156-178
		F	60- 68	69- 78	78- 90	88-101	97-111	107-122
	50-59	M	66- 75	79- 90	92-106	106-121	119-136	132-151
		F	53- 61	62- 70	70- 80	78- 90	87- 99	95-109
	60-69	M	58- 66	69- 79	81- 93	93-106	104-119	116-133
		F	46- 53	55- 62	62- 70	69- 78	77- 88	84- 96